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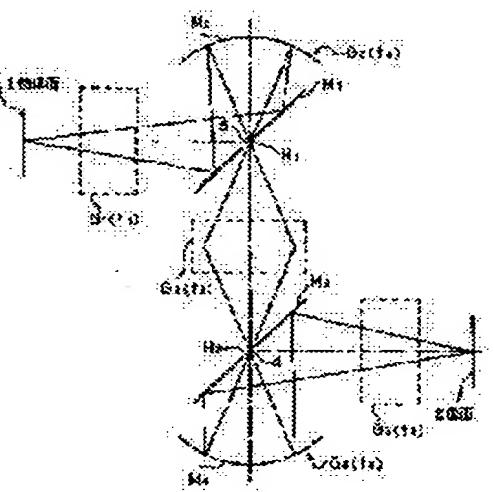
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(54) REFLECTION/REFRACTION/PROJECTION OPTICAL SYSTEM

(57)Abstract:

PURPOSE: To provide a reflection/refraction/projection optical system with superior image-forming performance without using a beam splitter and capable of employing a batch exposure system.
CONSTITUTION: Light from a pattern on an object surface 1, after being reflected on the peripheral part of a first plane mirror M1 via a first convergence group G1, arrives at a second convergence group G2 consisting of a first concave reflecting mirror M2, and light reflected on the second convergence group G2 image-forms the intermediate image of the pattern in the aperture of the first plane mirror M1. Light from the first intermediate image image-forms the second intermediate image of the pattern in the aperture of a second plane mirror M3, and light from the second intermediate image arrives at a fourth convergence group G4 consisting of a second concave plane reflecting mirror M4, and light reflected on the fourth convergence group G4 is reflected in the periphery of the second plane mirror M3, and reflected light image-forms the third intermediate image of the pattern on the surface of an image surface 2 via a fifth convergence group G5.



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[JP,06-265789,A]

CLAIMS

[Claim(s)]

[Claim 1] The part I part image formation optical system which is the optical system which projects the image of the pattern on the 1st page on the 2nd page, and carries out image formation of the medium image of the pattern on said 1st page, The part II part image formation optical system which carries out re-image formation of the image of said medium image on said 2nd page is arranged. One [at least] partial image formation optical system of said two partial image formation optical system The selection optical system by which image formation of said medium image is carried out to said the 1st field or 2nd field while reflecting the light of the 2nd field which is made to pass the light of the 1st field and is different from this 1st field, The reflective refraction projection optical system characterized by having the lieberkuhn which returns again the flux of light drawn through this selection optical system to this selection optical system, and the convergence group arranged between said 1st page and said selection optical system or between said selection optical system and said 2nd page.

[Claim 2] The part I part image formation optical system which is the optical system which projects the image of the pattern on the 1st page on the 2nd page, and carries out image formation of the medium image of the pattern on said 1st page, The part II part image formation optical system which carries out image formation of the image of said medium image on said 2nd page is arranged. Said part I part image formation optical system The selection optical system which reflects the light of the 2nd field which is aslant arranged to an optical axis, is made to pass the light of the 1st field, and is different from this 1st field, The 1st convergence group which leads the flux of light from the pattern on said 1st page to said selection optical system, It has the 1st lieberkuhn which reflects the flux of light reflected by said selection optical system, and carries out image formation of the medium image of said pattern into said 1st field of said selection optical system, or said 2nd field. Said part II part image formation optical system is a reflective refraction projection optical system characterized by having the 2nd lieberkuhn which returns again the flux of light from said medium image within said selection optical system to said selection optical system, and the 2nd convergence group which carries out image formation of the image of said medium image on said 2nd page from the flux of light again reflected by said selection optical system.

[Claim 3] Focal distance f_1 which is the optical system which projects the image of the

pattern on the 1st page on the 2nd page, and converges the flux of light from the pattern on said 1st page in order [page / said / 1st] The 1st convergence group, The 1st selection optical system which reflects the light of the 2nd field which is made to pass the light of the 1st field and is different from this 1st field, and leads the flux of light from said 1st convergence group to consecutive optical system, Focal distance f_2 which reflects the flux of light from said 1st selection optical system, and carries out image formation of the 1st medium image of said pattern including the 1st lieberkuhn into said 1st field of said 1st selection optical system, or said 2nd field The 2nd convergence group, Focal distance f_3 which converges the flux of light from said 1st medium image, and carries out image formation of the 2nd medium image of said pattern While reflecting the light of the 2nd field which is made to pass the 3rd convergence group and the light of the 1st field, and is different from this 1st field this 1st field -- or -- this -- with the 2nd selection optical system by which image formation of said 2nd medium image is carried out into the 2nd field Focal distance f_4 which returns the flux of light from said 2nd medium image to said 2nd selection optical system including the 2nd lieberkuhn The 4th convergence group, Focal distance f_5 which converges the flux of light drawn according to said 2nd selection optical system, and carries out image formation of the 3rd medium image of said pattern on said 2nd page Reflective refraction projection optical system characterized by having the 5th convergence group.

[Claim 4] Said 1st selection optical system and said 2nd selection optical system are a reflective refraction projection optical system according to claim 3 characterized by being the reflecting mirror with which it has opening of a predetermined configuration, respectively, and image formation of the medium image of said pattern is carried out into this opening, respectively.

[Claim 5] Said 1st selection optical system and said 2nd selection optical system are a reflective refraction projection optical system according to claim 3 characterized by being the small reflecting mirror with which it has the reflective section of a predetermined configuration, respectively, and image formation of the medium image of said pattern is carried out to these reflective circles, respectively.

[Claim 6] said 1st convergence group - the PETTSU bar sum according to individual of said 5th convergence group -- respectively -- $p_1 \cdot p_5$ ** -- the time of carrying out -- $p_1+p_3+p_5 > 0$ and -- Reflective refraction projection optical system according to claim 3, 4, or 5 characterized by satisfying the conditions of $p_2+p_4 < 0$.

[Claim 7] The reflective refraction projection optical system according to claim 3, 4, 5, or 6 characterized by satisfying the conditions of $0.1 \leq |\beta_{12}| \leq 2$ when the image formation scale factor of said 1st medium image by said 1st convergence group and the

2nd convergence group is set to beta 12.

[Claim 8] It is an image formation scale factor from said 1st medium image by said 3rd convergence group to said 2nd medium image beta 3 Reflective refraction projection optical system according to claim 3 to 7 characterized by satisfying the conditions of $0.1 \leq |\beta_3| \leq 2$ when it carries out.

[Claim 9] The reflective refraction projection optical system according to claim 3 to 8 characterized by satisfying the conditions of $0.1 \leq |\beta_{45}| \leq 2$ when the image formation scale factor from said 2nd medium image by said 4th convergence group and the 5th convergence group to said 3rd medium image is set to beta 45.

[Claim 10] The reflective refraction projection optical system according to claim 3 to 9 characterized by having set the periphery of a field to which image formation of said 1st medium image is carried out within said 1st selection optical system, and the pupil surface of said 3rd convergence group as conjugate relation, and setting the periphery of the field where image formation of said 2nd medium image is carried out to the pupil surface of said 3rd convergence group within said 2nd selection optical system as conjugate relation.

[Claim 11] It is the focal distance f_1 of said 1st convergence group about spacing with the location where image formation of said 1st medium image is carried out to the backside [said 1st convergence group] principal point within said 1st selection optical system. Reflective refraction projection optical system according to claim 3 to 10 characterized by setting up almost equally and making it become telecentric optical system mostly by said 1st page side.

[Claim 12] It is the focal distance f_5 of said 5th convergence group about spacing with the location where image formation of said 2nd medium image is carried out to the before [said 5th convergence group] side principal point within said 2nd selection optical system. Reflective refraction projection optical system according to claim 3 to 11 characterized by setting up almost equally and making it become telecentric optical system mostly by said 2nd page side.

[Claim 13] It is the focal distance f_1 of said 1st convergence group about spacing with the location where image formation of said 1st medium image is carried out to the backside [said 1st convergence group] principal point within said 1st selection optical system. It sets up almost equally. It is the focal distance f_5 of said 5th convergence group about spacing with the location where image formation of said 2nd medium image is carried out to the before [said 5th convergence group] side principal point within said 2nd selection optical system. It sets up almost equally. The reflective refraction projection optical system according to claim 3 to 12 characterized by making it become

telecentric optical system mostly by said said 1st page and 2nd page side, respectively.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Industrial Application] This invention relates to the reflective refraction projection optical system which has the resolution of a submicron unit in an ultraviolet-rays wavelength region by applying to the actual size of the projection aligner used in case a semiconductor device or a liquid crystal display component is manufactured at a photolithography process, or the projection optical system for cutback projection, and using a reflective system as an element of optical system especially about a suitable reflective refraction projection optical system.

[0002]

[Description of the Prior Art] In case a semiconductor device or a liquid crystal display component is manufactured at a photolithography process, a photo mask or the pattern image of reticle (it is hereafter named "reticle" generically) is reduced to about 1/5 through a projection optical system, and the projection aligner exposed on the substrates (a wafer, glass plate, etc.) with which sensitization material (photoresist etc.) was applied is used. The resolution required of the projection optical system currently used for the projection aligner is increasing increasingly as degrees of integration, such as a semiconductor device, improve.

[0003] In order to satisfy this demand, wavelength of the illumination light must be short-wavelength-ized, and numerical aperture (NA) of a projection optical system must be enlarged. However, if the wavelength of the illumination light becomes short, since it is the absorption of light, the class of ** material which is equal to practical use will be restricted. Especially the ** material that can be practically used if wavelength is set to 300nm or less serves as only synthetic quartz and fluorite. Since it is not separated from it so that both Abbe number is enough to amend chromatic aberration, when wavelength is set to 300nm or less, with having constituted the projection optical system only from refractive media, chromatic-aberration amendment becomes very difficult. Moreover, since the change property of the refractive index by the temperature change and the so-called temperature characteristic are bad, are on processing of lens polish further and have many problems, fluorite cannot use fluorite for many parts. Therefore, it is dramatically difficult to form the projection optical system which has the

resolution demanded only by refractive media.

[0004] On the other hand, although to constitute a projection optical system only from a reflective system is also tried in order that a reflective system may not have chromatic aberration, a projection optical system is enlarged in this case, and aspheric surface-ization of a reflector is needed. That is, it is also very difficult to constitute a projection optical system only from a reflective system. Then, the technique which constitutes a cutback projection optical system from so-called cata-dioptic system which combined a reflective system and refractive media is proposed variously. By JP,63-163319,A, ring visual field optical system is proposed as the example. It consists of this ring visual field optical system, using axial outdoor daylight so that only the zona-orbicularis section besides a shaft may be exposed, so that incident light and the reflected light may not interfere mutually.

[0005] Moreover, the cutback projection mold aligner equipped with the cata-dioptic system which bundles up using the flux of light near a shaft top, and projects the image of reticle is proposed as another example by arranging the beam splitter which consists of half mirrors inside in JP,51-27116,B or JP,2-66510,A.

[0006]

[Problem(s) to be Solved by the Invention] Among the Prior arts like the above, by ring visual field optical system, in order to avoid interference with incident light and the reflected light, while it is required to reflect the flux of light repeatedly using many mirrors, therefore the whole optical system becomes complicated, there is inconvenience that it is difficult to enlarge numerical aperture.

[0007] And since exposure area could not expose the pattern of reticle for example, on the wafer by package narrowly, either, the so-called scanning exposure exposed while moving reticle and a wafer at a mutually different rate according to the cutback scale factor of a projection optical system needed to be performed. For this reason, the configuration of the device section of a projection aligner became complicated, and it was disadvantageous in respect of a manufacturing cost and exposure precision. That is, by the scanning exposure method, it is difficult overly to expose a detailed pattern to high degree of accuracy on a wafer, and it could not but turn into what also has a very high manufacturing cost.

[0008] In the conventional cata-dioptic system which bundles up using the flux of light near a shaft top, and projects the image of reticle on the other hand, there was inconvenience that there were many flares by the internal reflection by the reflected light from a wafer side and the internal reflection in the refracting interface of the optical system after a beam splitter. Furthermore, if there was inconvenience that the

phase change of the light in the heterogeneity of the reflection property of the beam splitter by change of whenever [angle-of-incidence / of the flux of light], the absorption of light by the reflective film, and the reflective film, the heterogeneity of the reflective film itself, etc. degraded an image formation property, the synthetic resolution as a projection optical system deteriorated and resolution was enough especially as a projection optical system of the aligner for semi-conductor manufacture, there was nothing. Moreover, because of the quantity of light loss by the beam splitter, the utilization effectiveness of light became the low thing which is 25% - about 10%, and it was not able to be said that it was practical.

[0009] This invention aims at offering the reflective refraction projection optical system which was excellent in the image formation engine performance which can take an one-shot exposure method unlike the ring visual field optical system which is constituted using a reflective system and refractive media, and exposes only the zona-orbicularis section using an axial outdoor daylight bundle, without using the beam splitter which consists of half mirrors in view of this point.

[0010]

[Means for Solving the Problem] As the 1st reflective refraction projection optical system by this invention is shown in drawing 1 The part I part image formation optical system which is the optical system which projects the image of the pattern on the 1st page (1) on the 2nd page (2), and carries out image formation of the medium image (3) of the pattern on the 1st page (1), The part II part image formation optical system which carries out re-image formation of the image of a medium image (3) on the 2nd page (2) is arranged. One [at least] partial image formation optical system of these two partial image formation optical system selection optical system M1 by which image formation of the medium image (3) is carried out to these 1st fields or the 2nd field while reflecting the light of the 2nd field which is made to pass the light of the 1st field and is different from this 1st field Lieberkuhn M2 which returns again the flux of light drawn through this selection optical system to this selection optical system The 1st page (1) and selection optical system M1 Between or selection optical system M1 Convergence group G1 arranged between the 2nd page (2) It has.

[0011] In addition, for the optical system of drawing 1 , the part I part image formation optical system is the lieberkuhn M2. Although it is the example which it has, the part II part image formation optical system is the lieberkuhn M4. The example which it has is the optical system of drawing 2 . That is, both the optical system of drawing 1 and the optical system of drawing 2 belong to the 1st reflective refraction projection optical system of this invention.

[0012] The 2nd reflective refraction projection optical system Moreover, for example, the part I part image formation optical system which is the optical system which projects the image of the pattern on the 1st page (1) on the 2nd page (2), and carries out image formation of the medium image (3) of the pattern on the 1st page (1) as shown in drawing 3 . The part II part image formation optical system which carries out image formation of the image of a medium image (3) on the 2nd page (2) is arranged. The part I part image formation optical system selection optical system M1 which reflects the light of the 2nd field which is aslant arranged to an optical axis, is made to pass the light of the 1st field, and is different from this 1st field the flux of light from the pattern on the 1st page (1) -- selection optical system M1 The 1st convergence group G1 to draw Selection optical system M1 The reflected flux of light is reflected and it is the selection optical system M1. The 1st lieberkuhn M2 which carries out image formation of the medium image (3) of the pattern into the 1st field or its 2nd field It has. The part II part image formation optical system is the selection optical system M1. It is the selection optical system M1 again about the flux of light from an inner medium image (3). The 2nd lieberkuhn M4 to return Selection optical system M1 The 2nd convergence group G5 which carries out image formation of the image of a medium image (3) on the 2nd page (2) from the flux of light reflected again It has.

[0013] Moreover, the 3rd reflective refraction projection optical system is optical system which projects the image of the pattern on the 1st page (1) on the 2nd page (2), as shown in drawing 4 . focal distance f1 which converges the flux of light from the pattern on the 1st page (1) in order [page / (1) / 1st] The 1st convergence group G1 the light of the 2nd field which is made to pass the light of the 1st field and is different from this 1st field -- reflecting -- the 1st convergence group G1 from -- the 1st selection optical system M1 which leads the flux of light to consecutive optical system the 1st lieberkuhn M2 containing -- the 1st selection optical system M1 from -- the flux of light -- reflecting -- the 1st selection optical system M1 Focal distance f2 which carries out image formation of the 1st medium image (3) of the pattern into the 1st field or its 2nd field The 2nd convergence group G2 Focal distance f3 which converges the flux of light from the 1st medium image (3), and carries out image formation of the 2nd medium image (4) of the pattern 3rd convergence group G3 While reflecting the light of the 2nd field which is made to pass the light of the 1st field and is different from this 1st field this 1st field -- or -- this -- the 2nd selection optical system M3 by which image formation of the 2nd medium image (4) is carried out into the 2nd field the 2nd lieberkuhn M4 containing -- the flux of light from the 2nd medium image (4) -- the 2nd selection optical system M3 Focal distance f4 to return The 4th convergence group G4 The 2nd selection optical

system M3 Focal distance f5 which converges the drawn flux of light and carries out image formation of the 3rd medium image of the pattern on the 2nd-page (2) The 5th convergence group G5 It has.

[0014] In this case, that 1st selection optical system and an example of that 2nd selection optical system are reflecting mirrors (M1 and M3) with which it has opening (H1 and H2) of a predetermined configuration, respectively, and image formation of the medium image (3 4) of that pattern is carried out into these openings, respectively, as shown in drawing 4.

[0015] Moreover, the 1st selection optical system and other examples of the 2nd selection optical system are small reflecting mirrors (M1', M3') with which it has the reflective section of a predetermined configuration, respectively, and image formation of the medium image (3 4) of the pattern is carried out to these reflective circles, respectively, as shown in drawing 5. Therefore, the optical system of drawing 4 and the optical system of drawing 5 are optically equivalent.

[0016] In this case, the optical system of drawing 1 is optical system to the 2nd selection optical system M3 of drawing 4 - the 5th convergence group G5. It is equivalent to what was excluded and the optical system of drawing 2 is the optical system of drawing 4 to the 1st convergence group G1 - the 1st selection optical system M1. It is equivalent to what was excluded. Moreover, the optical system of drawing 3 is the optical system of drawing 4 to 3rd convergence group G3. It is equivalent to what was excluded. Therefore, the 1st and 2nd reflective refraction projection optical systems by this invention are the 3rd reflective refraction projection optical system according to this invention respectively to convergence group G1 -G5. And selection optical system M1 and M2 It is possible that which the inner element was excluded. And convergence groups G1-G5 excluded in this way By considering that the PETTSU bar sum is 0, the conditions imposed to the 3rd reflective refraction projection optical system of this invention in following conditional-expression (1) - (10) are applied also to the 1st [of this invention], and 2nd reflective refraction projection optical systems, respectively.

[0017] That is, they are the 1st convergence group G1 - the 5th convergence group G5 first. It is the PETTSU bar sum according to individual, respectively p1 -p5 When it carries out, it is desirable to satisfy the following conditions.

$$p1+p3+p5 >0 \text{ and } p2+p4 <0 \quad (1)$$

[0018] Moreover, the 1st convergence group G1 And the 2nd convergence group G2 When beta 12 and the image formation scale factor of the whole system are set to beta for the image formation scale factor of the 1st medium image (3) to twist, it is desirable to satisfy the following conditions.

$0.1 \leq |\beta_{12}| \leq 2$ (2)

moreover, 3rd convergence group G3 the image formation scale factor from the 1st medium image (3) to the 2nd medium image (4) to twist β_3 ** when it carries out, it is desirable to satisfy the following conditions.

[0019]

$0.1 \leq |\beta_{13}| \leq 2$ (3)

[0020] Furthermore, the 4th convergence group G4 And the 5th convergence group G5 When the image formation scale factor from the 2nd medium image (3) to the 3rd medium image (4) to twist is set to β_{45} , it is desirable to satisfy the following conditions.

$0.1 \leq |\beta_{45}| \leq 2$ (4)

Moreover, the 1st selection optical system M1 Field H1 where image formation of the medium image (3) is carried out inside A periphery and 3rd convergence group G3 A pupil surface is set as conjugate relation and it is 3rd convergence group G3. A pupil surface and the 2nd selection optical system M3 Field H2 where image formation of the medium image (4) is carried out inside It is desirable to set a periphery as conjugate relation.

[0021] Furthermore, the 1st convergence group G1 The backside principal point and the 1st selection optical system M1 It is the 1st convergence group G1 about spacing with the location where image formation of the medium image (3) is carried out inside. Focal distance f_1 It is desirable to set up almost equally and to become telecentric optical system mostly by the 1st page (1) side. Moreover, the 5th convergence group G5 The before side principal point and the 2nd selection optical system M3 It is the 5th convergence group G5 about spacing with the location where image formation of the medium image (4) is carried out inside. Focal distance f_5 It is desirable to set up almost equally and to become telecentric optical system mostly by the 2nd page (2) side.

[0022] Moreover, the 1st convergence group G1 The backside principal point and the 1st selection optical system M1 It is the 1st convergence group G1 about spacing with the location where image formation of the medium image (3) is carried out inside. Focal distance f_1 It sets up almost equally. The 5th convergence group G5 The before side principal point and the 2nd selection optical system M3 It is the 5th convergence group G5 about spacing with the location where image formation of the medium image (4) is carried out inside. Focal distance f_5 It is desirable to set up almost equally and to become telecentric optical system mostly by the 1st page (1) and 2nd page (2) side, respectively.

[0023]

[Function] According to the 1st reflective refraction projection optical system of this invention, the medium image (3) of the pattern on the 1st page (1) by the part I part image formation optical system is relayed by the part II part image formation optical system on the 2nd page (2). Moreover, it is the lieberkuhn M2 in either [at least] the part I part image formation optical system or the part II part image formation optical system. It is used and they are refractive media and its lieberkuhn M2. As a means which bends the optical path of a between Selection optical system M1, such as a small reflecting mirror (for example, M1 ' of drawing 5) which reflects light in the center only in the reflecting mirror (for example, M1 of drawing 1) or center section which has opening It is used and is this selection optical system M1. Image formation of the medium image (3) is carried out to the center section. Therefore, since the beam splitter of a half mirror mold with much futility of the illumination light is not used while becoming the cause of the conventional flare etc., the great portion of flux of light can be used effectively. In addition, in the optical system of drawing 1 - drawing 5 , a body side and the 2nd page (2) are displayed for the 1st page (1) as the image surface, respectively. [0024] of course, selection optical system M1 It has the description that a part of flux of light near an optical axis serves as optical system which has a zona-orbicularis-like pupil in order to be kicked and not to contribute to image formation, and various image formation properties become what was alike and changed with the shield factor at that time. However, also in the projection aligner which uses the usual dioptric system without the covered section as a projection optical system, change of the image the so-called deformation light source method which covers the light near the optical axis of an illumination-light study system specially, and raises resolution is proposed, and according to change of an image formation property is suppliable with recently with the property of sensitization material, and the design of reticle.

[0025] While there is less total quantity of light loss than it compared with what uses a half mirror, the advantage of one-shot exposure being made and not needing complicated scanning exposure is larger. Moreover, according to the 2nd reflective refraction projection optical system of this invention, as shown, for example in drawing 3 The 1st lieberkuhn M2 The medium image (3) of the pattern on the 1st page (1) by the part I part image formation optical system which it has is the selection optical system M2. Image formation is carried out near the optical axis, and this medium image (3) is the 2nd lieberkuhn M4. It is relayed on the 2nd page (2) by the part II part image formation optical system which it has. Therefore, since the beam splitter of a half mirror mold is not used, the great portion of flux of light can be used effectively. Furthermore, since two lieberkuhn (M2, M4) is used, the radius of curvature of each lieberkuhn can be

doubled compared with the case where one lieberkuhn is used, and many aberration reduces it.

[0026] Moreover, according to the 3rd reflective refraction projection optical system of this invention, as shown, for example in drawing 4 The 1st convergence group G1 It reaches and is mainly the 1st lieberkuhn M2. The 2nd convergence group G2 constituted The 1st medium image (3) of the pattern on the 1st page (1) to depend is the 1st selection optical system M1. Image formation is carried out near the optical axis. The 1st medium image (3) is 3rd convergence group G3. The 2nd selection optical system M3 It is relayed as the 2nd medium image (4) near the optical axis, and the 2nd medium image (4) is mainly the 2nd lieberkuhn M4. The 4th convergence group G4 constituted And the 5th convergence group G5 It is relayed on the 2nd page (2). Therefore, since the beam splitter of a half mirror mold is not used, while being able to use effectively the great portion of flux of light, the flare etc. decreases in number.

[0027] Moreover, 3rd convergence group G3 which relays the 1st medium image (3) to the 2nd medium image (4) Since it is prepared, control ranges, such as a projection scale factor or many aberration, spread. In addition, as the 1st selection optical system and its 2nd selection optical system, as shown in drawing 4 As it has opening (H1 and H2) of a predetermined configuration, respectively and is indicated in drawing 5 as the case where the reflecting mirror (M1 and M3) with which image formation of the medium image (3 4) of the pattern is carried out into these openings, respectively is used It is optically equivalent to the case where the small reflecting mirror (M1', M3') with which it has the reflective section of a predetermined configuration, respectively, and image formation of the medium image (3 4) of the pattern is carried out to these reflective circles, respectively is used.

[0028] Next, in this 3rd reflective refraction projection optical system, in order to make the image formation engine performance to improvement and to make the image surface into flatness more, the PETTSU bar sum of the whole optical system must be first made into the zero neighborhood. If there is no PETTSU bar sum in the zero neighborhood, a projection image side will not become flat but will become the curved thing. For this reason, the 1st convergence group G1 · the 5th convergence group G5 It is a focal distance, respectively f1, f2, f3, and f4 And f5 It carries out. It is the PETTSU bar sum of each group, respectively p1, p2, p3, and p4 And p5 It is the refractive index (value which broke the focal distance of each group by the PETTSU bar sum of each [these] group) to which carries out and only each group is applied, respectively n1, n2, n3, and n4 And n5 When it carries out, it is desirable to materialize the following relation.

[0029]

$-0.01 \leq p1 + p2 + p3 + p4 + p5 < 0.01$ (5)

[0030] If the image surface does not become flat enough unless it satisfies this formula, but the image surface carries out the bow of concave to the 1st page (1) if a minimum is exceeded, and an upper limit is exceeded, the image surface carries out the bow of a convex to the 1st page (1). In order to be satisfied with this invention of the conditions of the (5) type, he divides the PETTSU bar sum of the whole system into the 1st partial sum ($p1 + p3 + p5$) and 2nd partial sum ($p2 + p4$), and is trying to become a reverse sign as each partial sum shows on condition that (1) type.

[0031] In this case, $p1$ and $p3$ of the PETTSU bar sums of each group And $p5$ It is expressed as follows, respectively.

$$p1 = 1/(f1 n1) \quad (6)$$

$$p3 = 1/(f3 n3) \quad (7)$$

$$p5 = 1/(f5 n5) \quad (8)$$

[0032] Especially, it is the PETTSU bar sum $p2$ of two groups and four groups. And $p4$ It is desirable to attach and to fulfill the following conditions.

$$0 \leq n_{two} p2 \leq 2 / |R2| \quad (9)$$

$0 \leq n_{four} p4 \leq 2 / |R4| \quad (10)$ [0033] It sets at these (9) formulas and (10) ceremony, and is $R2$. The 2nd convergence group $G2$ The 1st lieberkuhn $M2$ which constitutes a part It is radius of curvature. $n2$ The 2nd convergence group $G2$ It is the refractive index which applying accepts and is $R4$ similarly. The 4th convergence group $G4$ It is the radius of curvature of the 2nd lieberkuhn $M4$ which constitutes a part, and is $n4$. The 4th convergence group $G4$ It is the refractive index which applying accepts. (9) In a formula and (10) types, if a minimum is exceeded, respectively, the PETTSU bar sum of the whole system will just become too much, and if an upper limit is exceeded, it will become negative too much.

[0034] Moreover, the 1st convergence group $G1$ of optical system The 2nd convergence group $G2$ If the image formation scale factor of the first image formation to depend is set to beta 12 and the image formation scale factor of the whole system is set to beta (2) If it is desirable to satisfy the conditions of a formula and it exceeds the minimum of (2) types, it is the 1st selection optical system $M1$. Image formation field $H1$ of the upper 1st medium image It must take greatly, a shield factor increases, loss of the quantity of light becomes large, and the image formation engine performance worsens. If the upper limit of (2) types is exceeded, it is the 1st convergence group $G1$. The 2nd convergence group $G2$ The aberration in the first image formation to depend becomes large, and the image formation engine performance worsens too.

[0035] Moreover, 3rd convergence group G3 It is the image formation scale factor of the second image formation to depend beta 3 If it carries out (3) If it is desirable to satisfy the conditions of a formula and it exceeds the minimum of (3) types The 2nd selection optical system M3 Image formation field H2 of the upper 2nd medium image If it must take greatly and an upper limit is exceeded, the amount of loss of the quantity of light not only increases, but a shield factor increases and the image formation engine performance worsens. If the upper limit of (3) types is exceeded, it is 3rd convergence group G3. The aberration in the second image formation to depend becomes large, and the image formation engine performance worsens too.

[0036] Moreover, the 4th convergence group G4 The 5th convergence group G5 If it is desirable to satisfy the conditions of (3) types if the image formation scale factor of the 3rd image formation to depend is set to beta 45 and it exceeds the minimum of (4) types, it is the 4th convergence group G4. The 5th convergence group G5 The aberration in the 3rd image formation to depend becomes large, and the image formation engine performance worsens. Field H2 where image formation of the 2nd medium image (4) is carried out on the 2nd selection optical system M3 if the upper limit of (4) types is exceeded It must take greatly, a shield factor increases, the amount of loss of the quantity of light increases, and the image formation engine performance worsens.

[0037] moreover, 3rd convergence group G3 the location (the location at which the flux of light is not extracted actually here and a chief ray crosses an optical axis is said) of the aperture diaphragm in inside -- a pupil surface s -- then The 1st selection optical system M1 Field H1 A periphery to the 2nd convergence group G2 It reflects, passes along a field H1 again, and is 3rd convergence group G3. The optical path which reaches the inner pupil surface s is in the relation between a body and an image. That is, field H1 As for a periphery and a pupil surface s, it is desirable to have a conjugate relation. Furthermore, a pupil surface s to the 2nd selection optical system M3 Field H2 It passes and is ***** G4. It is reflected and is a field H2 again. The optical path which reaches a periphery is also in the relation between a body and an image, and they are a pupil surface s and a field H2. As for a periphery, it is desirable to have a conjugate relation.

[0038] moreover -- for example, the optical path which reaches the periphery of 3rd convergence group G3 as shown in drawing 3 is also in the relation between a body and an image. the omitted optical system -- setting -- the 1st selection optical system M1 Field H1 pass a periphery -- the 2nd convergence group G2 reflecting -- again -- field H1 a passage -- after that -- the 4th convergence group G4 it reflects -- having -- again -- field H1 That is, field H1 One periphery and field H1 of a field As for the periphery of

the field of another side, it is desirable to have a conjugate relation.

[0039] moreover -- for example, the optical path which reaches the pupil surface s in the 4th convergence group G4 as shown in drawing 1 is in the relation between a body and an image. And the 5th convergence group G5 the omitted optical system -- setting -- the 1st selection optical system M1 Field H1 pass a periphery -- the 2nd convergence group G2 after being reflected -- again -- field H1 a passage -- 3rd convergence group G3 That is, field H1 As for a periphery and a pupil surface s, it is desirable to have a conjugate relation.

[0040] Moreover, the optical path which reaches the 1st convergence group G1 as shown, for example in drawing 2 is also in the relation between a body and an image. And the 2nd convergence group G2 It sets to the omitted optical system and is 3rd convergence group G3. It comes out of the inner pupil surface s, and is the 2nd selection optical system M3. Field H2 It passes and is the 4th convergence group G4. After being reflected, it is a field H2 again. That is, a pupil surface s and a field H2 As for a periphery, it is desirable to have a conjugate relation.

[0041] When conjugation relation which was described above temporarily collapses, it is a field H1. Or field H2 Since the covered part of the pupil surface s to depend shifts from the center of a pupil corresponding to image quantity, the inconvenience that the image formation property of optical system will change with image quantities arises. Moreover, the optical system of an illumination system does not become it large that it is **** telecentric optical system, but it is convenient for the 1st page (1) side. And even if the distance to the sensitization substrate on the 2nd page (2) changes somewhat that it is **** telecentric optical system to the 2nd page (2) side, there is no change of a scale factor, even if it performs many-layers thing pile baking, a gap of a dimension is lost, and it is convenient.

[0042] Furthermore, even if an illumination-light study system does not become it large that it is **** telecentric optical system, respectively at the 1st page (1) and 2nd page (2) side and the distance to the sensitization substrate on the 2nd page (2) changes somewhat, there is no change of a scale factor, even if it performs many-layers thing pile baking, a gap of a dimension is lost, and it is convenient.

[0043]

[Example] Hereafter, with reference to a drawing, it explains per various examples of the reflective refraction projection optical system by this invention. This example applies this invention to the projection optical system of the projection aligner which projects the image of the pattern of reticle for a predetermined scale factor (actual size is included) on the wafer with which it was applied to the photoresist.

[0044] Lens arrangement is expressed with the following examples in expansion optical-path drawing, as shown in drawing 6. In expansion optical-path drawing, a reflector is expressed as a transparency side and each optical element is arranged by the order which the light from reticle 10 passes. Moreover, in the part (for example, r9) of the lieberkuhn, a plane virtual side (for example, r10) is used. And as it is shown in drawing 6 since the configuration and spacing of a lens are expressed for example It is the radius of curvature r_i of the i -th page as the i -th page ($i = 1, 2, \dots$) one by one about the field through which it will pass by the time the light which made the pattern side of reticle 10 the 0th page, and was injected from reticle 10 reaches a wafer 11. A sign just takes the case of a convex to reticle 10 in expansion optical-path drawing. Moreover, it is d_i about the spacing of the i -th page and a $** (i+1)$ side. It carries out. Moreover, it is CaF₂ as $**$ material. Fluorite and SiO₂ Quartz glass is expressed, respectively. The refractive index to the criteria-for-use-of-food-additives wavelength (248nm) of quartz glass and fluorite is as follows.

Quartz glass: 1.508327 fireflies Stone : 1.467845 [0045] Moreover, the criteria-for-use-of-food-additives wavelength of the refractive index of quartz glass is as follows in 193nm.

Quartz glass: 1.56100 [0046] The [1st example] This 1st example is the projection optical system of actual size. The following example [example / this / 1st / 3rd] is an example corresponding to the optical system of drawing 4. As drawing 6 is expansion optical-path drawing of the projection optical system of the 1st example and it is shown in this drawing 6 The light from the pattern on reticle 10 is the 1st convergence group G1. The 1st plane mirror M1 which passed and was installed in the center at 45 degrees to the optical axis with opening After being reflected by the periphery, The 1st lieberkuhn M2 The becoming 2nd convergence group G2 It results and is the 2nd convergence group G2. The reflected light is the 1st plane mirror M1. Image formation of the 1st medium image of the pattern is carried out into opening. And 3rd convergence group G3 in which the light from this 1st medium image has the lieberkuhn M31 Pass. The 2nd plane mirror M3 installed in the center at 45 degrees to the optical axis with opening Image formation of the 2nd medium image of the pattern is carried out into opening. The light from this 2nd medium image is the 2nd lieberkuhn M4. The becoming 4th convergence group G4 It results and is the 4th convergence group G4. The reflected light is the 2nd plane mirror M3. It is reflected on the outskirts. Thus, the reflected light is the 5th convergence group G5. It passes and image formation of the 3rd medium image of the pattern is carried out to the front face of a wafer 11.

[0047] Moreover, drawing 7 is the 1st convergence group G1 in drawing 6. As a detailed

configuration is shown and it is shown in this drawing 7, it is the 1st convergence group G1. It consists of positive meniscus lenses L14 which turned the convex to the positive meniscus lens L11 which turned the convex to reticle 10, a biconvex lens (only henceforth a "convex lens") L12, the positive meniscus lens L13 which turned the concave surface to reticle 10, and reticle 10 sequentially from the reticle 10 side. Moreover, as shown in drawing 6, it is 3rd convergence group G3. It consists of positive meniscus lenses L32 which turned the concave surface to the positive meniscus lens L31, the lieberkuhn M31, and reticle 10 which turned the concave surface to reticle 10, and is the 5th convergence group G5. The 1st convergence group G1 It is constituted symmetrically.

[0048] That is, this example serves as optical system of the symmetry mold which consists of two the plane mirror, the lieberkuhn of three sheets, and ten dioptric lenses which have opening near the optical axis, and numerical aperture is [10mm and the maximum mirror radius of 0.45 and image quantity] 486mm. However, since it is the optical-character ability almost near non-aberration, it is clear that image quantity is expandable by twice to 3 times with proportion amplification of optical system.

[0049] Although all dioptric lenses are using one kind of optical glass which consists of fused quartzes, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 193nm of ultraviolet-rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration are also amended good. The radius of curvature r_i in the 1st example of drawing 6, and spacing d_i And ** material is shown in the following table 1. In the following tables, the 10th page, the 14th page, and the 18th page are virtual sides for expressing the lieberkuhn in expansion optical-path drawing, respectively.

[0050]

[A table 1]

i	r_i	d_i	material	i	r_i	d_i	material
0		15.5		15	137.56	53.0	
1	125.97	18.5	SiO_2	16	206.41	1148.7	
2	138.88	1.0		17	-1189.91	0.0	
3	425.68	19.0	SiO_2	18	∞	1188.0	
4	-190.98	7.0		19	-327.82	31.0	SiO_2
5	-69.10	7.0	SiO_2	20	-310.82	0.1	
6	-55.19	0.1		21	55.19	7.0	SiO_2
7	310.82	31.0	SiO_2	22	69.10	7.0	
8	327.82	1188.0		23	190.98	19.0	SiO_2
9	-1189.91	0.0		24	-425.68	1.0	
10	∞	1148.7		25	-138.88	18.5	SiO_2
11	-206.41	53.0	SiO_2	26	-125.97	15.4	
12	-137.56	1191.0					
13	-277.08	0.0					
14	∞	1191.0					

[0051] Moreover, in drawing 8 (a) - (c), longitudinal aberration drawing of the 1st example and drawing 8 (c) show chromatic aberration of magnification drawing of the 1st example, and drawing 8 (e) shows transverse aberration drawing of the 1st example. In these aberration drawings, Signs J, P, and Q show that operating wavelength is 248.4nm, 247.9nm, and 248.9nm, respectively. These aberration drawing shows that many aberration is amended good in the field of a large image circle, although a numerical aperture is as large as 0.45 in this example. Moreover, chromatic aberration is also amended good.

[0052] In addition, plane mirrors M1 and M3 which have opening in drawing 6 Even if it uses small plane mirror M1' as instead shown in drawing 5, respectively, and M3', it is as having already explained that equivalent optical system is realizable. Furthermore,

plane mirrors M1 and M3 Instead the concave mirror or convex mirror which has opening may be used, and a small concave mirror and a small convex mirror may be used further.

[0053] The [2nd example] This 2nd example is also an example of the projection optical system of actual size. As drawing 9 is expansion optical-path drawing of the projection optical system of the 2nd example and it is shown in this drawing 9 The light from the pattern on reticle 10 is the 1st convergence group G1. The 1st plane mirror M1 which passed and was installed in the center at 45 degrees to the optical axis with opening After being reflected by the periphery, The 1st lieberkuhn M2 The included 2nd convergence group G2 It results and is the 2nd convergence group G2. The reflected light is the 1st plane mirror M1. Image formation of the 1st medium image of the pattern is carried out into opening. And the light from this 1st medium image is 3rd convergence group G3. The 2nd plane mirror M3 which passed and was installed in the center at 45 degrees to the optical axis with opening Image formation of the 2nd medium image of that pattern is carried out into opening. The light from this 2nd medium image is the 2nd lieberkuhn M4. The included 4th convergence group G4 It results and is the 4th convergence group G4. The reflected light is the 2nd plane mirror M3. It is reflected on the outskirts. Thus, the reflected light is the 5th convergence group G5. It passes and image formation of the 3rd medium image of the pattern is carried out to the front face of a wafer 11.

[0054] Moreover, as shown in drawing 9 , it is the 1st convergence group G1. It consists of negative meniscus lenses L14 which turned the convex to a convex lens L11, a biconcave lens (only henceforth a "concave lens") L12, the positive meniscus lens L13 that turned the concave surface to reticle 10, and reticle 10 sequentially from the reticle 10 side, and is 2nd convergence group G3. The negative meniscus lens L21 and lieberkuhn M2 which turned the concave surface to reticle 10 It is the becoming Mangin mirror. Moreover, 3rd convergence group G3 It consists of a concave lens L31, a convex lens L32, a concave lens L33, the positive meniscus lens L34 that turned the concave surface to reticle 10, the negative meniscus lens L35 which turned the convex to reticle 10, the positive meniscus lens L36 which turned the concave surface to reticle 10, a convex lens L37, the negative meniscus lens L38 which turned the convex to reticle 10, convex lenses L39 and these lenses L31-L39, and symmetrical lens L3 A-L3I.

[0055] And the 4th convergence group G4 The negative meniscus lens L41 and the 2nd lieberkuhn M4 which turned the concave surface to reticle 10 It is the becoming Mangin mirror and is the 5th convergence group G5. The 1st convergence group G1 It is constituted symmetrically. That is, this example serves as optical system of the

symmetry mold which consists of two the plane mirror, the lieberkuhn of two sheets, and 28 dioptric lenses which have opening in the center, and numerical aperture is [5mm and the maximum mirror radius of 0.45 and image quantity] 75mm. However, since the optical-character ability almost near non-aberration is obtained, this example of enlarge [by proportion amplification of optical system / image quantity / with twice to 3 times / further] is also clear.

[0056] Moreover, the 2nd convergence group G2 And the 4th convergence group G4 The configuration of the Mangin mirror of the type with which a dioptric lens and the lieberkuhn were separated is taken including one negative meniscus lens, respectively. Thus, the 2nd lieberkuhn M2 The included 2nd convergence group G2 The optical glass of few classes can also remove the chromatic aberration on a shaft easily as it is the Mangin mirror containing a negative meniscus lens L21. Similarly, it is the 2nd lieberkuhn M4. The included 4th convergence group G4 Also when it is the Mangin mirror containing a negative meniscus lens L41, the optical glass of few classes can remove the chromatic aberration on a shaft easily.

[0057] Therefore, it is the 2nd convergence group G2 like this 2nd example. It is the Mangin mirror containing a negative meniscus lens, and is the 4th convergence group G4. When it is the Mangin mirror containing a negative meniscus lens, the optical glass of few [as a whole] classes can remove the chromatic aberration on a shaft easily. Although, as for all dioptric lenses, the optical system of this example is also using one kind of optical glass which consists of fused quartzes, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 248nm of ultraviolet-rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration also serve as optical system which was excellent in the image formation engine performance amended good.

[0058] The radius of curvature r_i in the 2nd example, and spacing d_i And ** material is shown in the following table 2. In the following tables, the 12th page and the 53rd page are virtual sides for expressing the lieberkuhn in expansion optical-path drawing, respectively.

[0059]

[A table 2]

i	r _i	d _i	material	i	r _i	d _i	material
0	—	12.0		33	129.52	15.0	SiO ₂
1	259.01	10.0	SiO ₂	34	-169.96	2.5	
2	-55.98	1.0		35	-213.06	7.5	SiO ₂
3	-77.91	7.0	SiO ₂	36	-437.70	0.1	
4	265.03	2.0		37	104.95	11.1	SiO ₂
5	-235.04	10.0	SiO ₂	38	-523.65	0.5	
6	-32.95	0.1		39	108.51	11.2	SiO ₂
7	383.80	10.0	SiO ₂	40	159.04	5.0	
8	190.09	161.5		41	-144.67	9.3	SiO ₂
9	-129.13	10.0	SiO ₂	42	-1584.18	0.3	
10	-222.54	12.0		43	56.77	11.2	SiO ₂
11	-158.01	0.0		44	182.94	2.1	
12	∞	12.0		45	-3429.20	7.5	SiO ₂
13	222.54	10.0	SiO ₂	46	35.03	0.3	
14	129.13	154.4		47	33.24	11.2	SiO ₂
15	-42.66	7.5	SiO ₂	48	-146.57	0.3	
16	862.47	0.3		49	-862.47	7.5	SiO ₂
17	146.57	11.2	SiO ₂	50	42.66	154.4	
18	-33.24	0.3		51	-129.13	10.0	SiO ₂
19	-35.03	7.5	SiO ₂	52	-222.54	12.0	
20	3429.20	2.1		53	∞	0.0	
21	-182.94	11.2	SiO ₂	54	158.01	12.0	
22	-56.77	0.3		55	222.54	10.0	SiO ₂
23	1584.18	9.3	SiO ₂	56	129.13	161.5	
24	144.67	5.0		57	-190.09	10.0	SiO ₂
25	-159.04	11.2	SiO ₂	58	-383.80	0.1	
26	-108.51	0.5		59	32.95	10.0	SiO ₂
27	523.65	11.1	SiO ₂	60	235.04	2.0	
28	-104.95	0.1		61	-265.03	7.0	SiO ₂
29	437.70	7.5	SiO ₂	62	77.91	1.0	
30	213.06	2.5		63	55.98	10.0	SiO ₂
31	169.96	15.0	SiO ₂	64	-259.01	11.9	
32	-129.52	135.0					

[0060] Moreover, in drawing 10 (a) - (c), longitudinal aberration drawing of the 2nd example and drawing 10 (c) show chromatic-aberration-of-magnification drawing of the 2nd example, and drawing 10 (e) shows transverse aberration drawing of the 2nd example. These aberration drawing shows that many aberration is amended good in the field of a large image circle, although a numerical aperture is as large as 0.45 also in this example. Moreover, chromatic aberration is also amended good.

[0061] The [3rd example] This 3rd example is an example of the projection optical system which performs cutback projection. As drawing 11 is expansion optical-path drawing of the projection optical system of the 3rd example and it is shown in this drawing 11 The light from the pattern on reticle 10 is the 1st convergence group G1. The 1st plane mirror M1 which passed and was installed in the center at 45 degrees to the optical axis with opening After being reflected by the periphery, The 2nd convergence group G2 containing the 1st lieberkuhn M2 It results and is the 2nd convergence group G2. The reflected light carries out image formation of the 1st medium image of the pattern into opening of the 1st plane mirror M1. And the light from this 1st medium image is 3rd convergence group G3. The 2nd plane mirror M3 which passed and was installed in the center at 45 degrees to the optical axis with opening Image formation of the 2nd medium image of that pattern is carried out into opening. The light from this 2nd medium image is the 2nd lieberkuhn M4. The included 4th convergence group G4 It results and is the 4th convergence group G4. The reflected light is the 2nd plane mirror M3. It is reflected on the outskirts. Thus, the reflected light is the 5th convergence group G5. It passes and image formation of the 3rd medium image of the pattern is carried out to the front face of a wafer 11.

[0062] Moreover, as shown in drawing 11 , it is the 1st convergence group G1. It consists of negative meniscus lenses L14 which turned the convex to the positive meniscus lens L11 which turned the concave surface to reticle 10, the negative meniscus lens L12 which turned the convex to reticle 10, a convex lens L13, and reticle 10 sequentially from the reticle 10 side, and is 2nd convergence group G3. The negative meniscus lens L21 and lieberkuhn M2 which turned the concave surface to reticle 10 It is the becoming Mangin mirror. moreover, 3rd convergence group G3 To reticle 10, a concave surface To the turned negative meniscus lens L31 and reticle 10, a concave surface To the turned positive meniscus lens L32 and reticle 10, a concave surface To the turned negative meniscus lens L33 and reticle 10, a concave surface The turned positive meniscus lens L34, the negative meniscus lens L35 which turned the convex to reticle 10, the positive meniscus lens L36 which turned the concave surface to reticle 10, the positive meniscus lens L37 which turned the concave surface to reticle 10, a convex lens L38, a convex lens

L39, convex lens L3A, Positive meniscus lens L3B which turned the convex to reticle 10, negative meniscus lens L3C which turned the concave surface to reticle 10, It consists of positive meniscus lens L3G which turned the convex to positive meniscus lens L3D which turned the convex to reticle 10, concave lens L3E, convex lens L3F, and reticle 10. [0063] and the 4th convergence group G4 The negative meniscus lens L41 and the 2nd lieberkuhn M4 which turned the concave surface to reticle 10 the becoming Mangin mirror -- it is -- the 5th convergence group G5 To reticle 10, a convex To the turned positive meniscus lens L51 and reticle 10, a convex It consists of positive meniscus lenses L55 which turned the convex to the turned negative meniscus lens L52, the positive meniscus lens L53 which turned the convex to reticle 10, the negative meniscus lens L54 which turned the concave surface to reticle 10, and reticle 10.

[0064] That is, this example consists of two the plane mirror, the lieberkuhn of two sheets, and 27 dioptric lenses which have opening in the center, and, for an image formation scale factor, 0.25 times and numerical aperture are [20mm and the maximum mirror radius of 0.45 and the body high] 75mm. Since this example also serves as optical-character ability almost near non-aberration, it is clear that image quantity can be further enlarged with twice to 3 times by proportion amplification of optical system. Moreover, the 2nd convergence group G2 And the 4th convergence group G4 The configuration of the Mangin mirror of the type with which the dioptric lens and the reflecting mirror were separated is taken including one negative meniscus lens, respectively.

[0065] Although, as for all dioptric lenses, the optical system of this example is also using one kind of optical glass which consists of fused quartzes, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 193nm of ultraviolet-rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration also serve as optical system which was excellent in the image formation engine performance amended good.

[0066] The radius of curvature r_i in the 3rd example, and spacing d_i And ** material is shown in the following table 3. In the following tables, the 12th page and the 49th page are virtual sides for expressing the lieberkuhn in expansion optical-path drawing, respectively.

[0067]

[A table 3]

i	r_i	d_i	material	i	r_i	d_i	material
0	—	10.0		33	172.29	11.0	SiO ₂
1	-71.38	8.0	SiO ₂	34	-944.95	0.5	
2	-61.85	35.0		35	99.77	11.2	SiO ₂
3	231.03	6.0	SiO ₂	36	319.67	4.0	
4	71.51	35.0		37	-143.57	9.0	SiO ₂
5	4288.57	12.0	SiO ₂	38	-2409.53	0.3	
6	-77.96	33.1		39	54.72	10.0	SiO ₂
7	552.21	6.0	SiO ₂	40	56.03	5.0	
8	78.03	170.0		41	-61.33	4.0	SiO ₂
9	-140.25	10.0	SiO ₂	42	45.57	1.5	
10	-215.61	39.9		43	50.21	12.0	SiO ₂
11	-186.04	0.0	SiO ₂	44	-46.06	0.3	
12	∞	39.9		45	26.02	7.5	SiO ₂
13	215.61	10.0	SiO ₂	46	113.79	127.3	
14	140.25	125.0		47	-130.37	10.0	SiO ₂
15	-16.54	5.0	SiO ₂	48	-279.95	35.9	
16	-72.83	0.3		49	∞	0.0	
17	-638.23	10.0	SiO ₂	50	167.11	35.9	
18	-33.20	5.0		51	279.95	10.0	SiO ₂
19	-23.16	5.0	SiO ₂	52	130.37	184.6	
20	-36.09	0.3		53	102.70	8.0	SiO ₂
21	-592.11	11.0	SiO ₂	54	298.78	0.5	
22	-56.28	0.3		55	31.06	8.0	SiO ₂
23	2342.59	7.0	SiO ₂	56	30.01	7.0	
24	97.46	7.0		57	56.85	7.5	SiO ₂
25	-363.12	11.0	SiO ₂	58	140.95	5.0	
26	-104.21	0.5		59	-92.02	7.0	SiO ₂
27	-1285.64	11.0	SiO ₂	60	-103.29	0.5	
28	-166.22	0.3		61	24.55	8.0	SiO ₂
29	116.73	15.0	SiO ₂	62	51.79	12.0	
30	-222.57	50.0					
31	945.64	14.0	SiO ₂				
32	-133.90	8.0					

[0068] Moreover, in drawing 12 (a) - (c), longitudinal aberration drawing of the 3rd example and drawing 12 (c) show chromatic-aberration-of-magnification drawing of the 3rd example, and drawing 12 (e) shows transverse aberration drawing of the 3rd example. These aberration drawing shows that many aberration is amended good in the field of a large image circle, although a numerical aperture is as large as 0.45 also in this example. Moreover, chromatic aberration is also amended good.

[0069] The [4th example] This 4th example is 3rd convergence group G3 while performing cutback projection. It is the projection optical system of the abridged type. That is, this example is an example corresponding to the optical system of drawing 3. As drawing 13 is expansion optical-path drawing of the projection optical system of the 4th example and it is shown in this drawing 13 The light from the pattern on reticle 10 is the 1st convergence group G1. Plane mirror M1 which passed and was installed in the center at 45 degrees to the optical axis with opening After being reflected by the surface periphery, The 1st lieberkuhn M2 The included 2nd convergence group G2 It results and is the 2nd convergence group G2. The reflected light is a plane mirror M1. Image formation of the medium image of the pattern is carried out into opening. And the light from this medium image is the 2nd lieberkuhn M4. The included 4th convergence group G4 It results and is the 4th convergence group G4. The reflected light is a plane mirror M1. It is reflected around a rear face. Thus, the reflected light is the 5th convergence group G5. It passes and image formation of the image of the pattern is carried out to the front face of a wafer 11. Plane mirror M1 of this example For example, the 1st plane mirror M1 of drawing 6 The 2nd plane mirror M3 It is equivalent to what was stuck.

[0070] Moreover, as shown in drawing 13 , it is the 1st convergence group G1. Sequentially from a reticle 10 side To reticle 10, a convex To the turned negative meniscus lens L11, a convex lens L12, the negative meniscus lens L13 which turned the convex to reticle 10, the positive meniscus lens L14 which turned the convex to reticle 10, the negative meniscus lens L15 which turned the convex to reticle 10, and reticle 10, a concave surface It consists of positive meniscus lenses L19 which turned the convex to the turned positive meniscus lens L16, a convex lens L17, the negative meniscus lens L18 which turned the concave surface to reticle 10, and reticle 10. 2nd convergence group G3 It is the Mangin mirror which consists of the negative meniscus lens L21 and lieberkuhn M2 which turned the concave surface to reticle 10.

[0071] moreover, the 4th convergence group G4 The negative meniscus lens L41 and the 2nd lieberkuhn M4 which turned the concave surface to reticle 10 the becoming Mangin mirror -- it is -- the 5th convergence group G5 To a convex lens L51 and reticle 10, a concave surface To the turned negative meniscus lens L52 and reticle 10, a convex To

the turned positive meniscus lens L53 and reticle 10, a convex It consists of the turned positive meniscus lens L54, the negative meniscus lens L55 which turned the convex to reticle 10, the convex lens L56, a negative meniscus lens L57 which turned the concave surface to reticle 10, a convex lens L58, and a concave lens L59.

[0072] That is, this example consists of one the plane mirror (plane mirror which stuck the plane mirror of two sheets on accuracy), the lieberkuhn of two sheets, and 20 dioptric lenses which have opening in the center, and, for an image formation scale factor, 0.2 times and numerical aperture are [25mm and the maximum mirror radius of 0.5 and the body high] 115mm. However, since this example also serves as optical-character ability almost near non-aberration, it is clear that image quantity can be further enlarged with twice to 3 times by proportion amplification of optical system. Moreover, the 2nd convergence group G2 And the 4th convergence group G4 The configuration of the Mangin mirror of the type with which the dioptric lens and the reflecting mirror were separated is taken including one negative meniscus lens, respectively.

[0073] In the optical system of this example, although the dioptric lens is using a fused quartz and two kinds of optical glass of fluorite, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 248nm of ultraviolet-rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration also serve as optical system which was excellent in the image formation engine performance amended good.

[0074] The radius of curvature r_i in the 4th example, and spacing d_i And ** material is shown in the following table 4. In the following tables, the 21st page and the 27th page are virtual sides for expressing the lieberkuhn in expansion optical-path drawing, respectively.

[0075]

[A table 4]

i	r_i	d_i	material	i	r_i	d_i	material
0	—	121.4		25	-440.69	17.0	SiO_2
1	767.44	15.0	SiO_2	26	-2852.06	12.0	
2	163.77	4.0		27	∞	0.0	
3	166.54	25.0	SiO_2	28	416.58	12.0	
4	-505.97	0.5		29	2852.06	17.0	SiO_2
5	233.77	18.0	SiO_2	30	440.69	432.6	
6	149.40	6.5		31	289.73	30.0	CaF_2
7	166.94	23.5	SiO_2	32	-246.70	3.5	
8	469.37	298.5		33	-193.54	10.0	SiO_2
9	606.70	15.0	SiO_2	34	-599.60	0.5	
10	238.92	20.0		35	144.65	20.0	CaF_2
11	-359.02	30.0	SiO_2	36	1180.27	0.5	
12	-210.62	100.0		37	94.98	32.0	CaF_2
13	3003.74	30.0	SiO_2	38	342.58	2.9	
14	-689.22	9.5		39	1588.35	12.0	SiO_2
15	-329.44	20.0	SiO_2	40	61.18	3.0	
16	-896.85	1.5		41	60.40	27.0	CaF_2
17	306.66	30.0	SiO_2	42	-523.49	2.5	
18	1333.63	447.0		43	-217.42	12.0	SiO_2
19	-414.75	17.0	SiO_2	44	-620.70	2.0	
20	-1772.13	12.0		45	62.05	18.0	CaF_2
21	∞	0.0		46	-518.54	2.0	
22	427.51	12.0		47	-653.52	10.0	SiO_2
23	1772.13	17.0	SiO_2	48	600.35	12.0	
24	414.75	652.6					

[0076] Moreover, in drawing 14 (a) - (c), longitudinal aberration drawing of the 4th example and drawing 14 (c) show chromatic aberration of magnification drawing of the 4th example, and drawing 14 (e) shows transverse aberration drawing of the 4th example. These aberration drawing shows that many aberration is amended good in the field of a large image circle, although a numerical aperture is as large as 0.45 also in this example. Moreover, chromatic aberration is also amended good.

[0077] The [5th example] This 5th example is the 4th convergence group G4 while performing cutback projection. And it is the projection optical system of the type which omitted the 5th convergence group G5. That is, this example is an example corresponding to the optical system of drawing 1. As drawing 15 is expansion optical-path drawing of the projection optical system of this 5th example and it is shown in this drawing 15 The light from the pattern on reticle 10 is the 1st convergence group G1. Plane mirror M1 which passed and was installed in the center at 45 degrees to the optical axis with opening After being reflected by the periphery, Lieberkuhn M2 The included 2nd convergence group G2 It results and is the 2nd convergence group G2. The reflected light is a plane mirror M1. Image formation of the medium image of the pattern is carried out into opening. And the light from this medium image is 3rd convergence group G3. It passes and image formation of the image of that pattern is carried out to the front face of a wafer 11.

[0078] Moreover, as shown in drawing 15 , it is the 1st convergence group G1. Sequentially from a reticle 10 side, it consists of the positive meniscus lens L11 which turned the convex to reticle 10, a negative meniscus lens L12 which turned the convex to reticle 10, a convex lens L13, and a concave lens L14, and is 2nd convergence group G3. The negative meniscus lens L21 and lieberkuhn M2 which turned the concave surface to reticle 10 It is the becoming Mangin mirror. moreover, 3rd convergence group G3 To reticle 10, a concave surface To the turned positive meniscus lens L31 and reticle 10, a concave surface To the turned positive meniscus lens L32, a convex lens L33, the negative meniscus lens L34 which turned the convex to reticle 10, a convex lens L35, a convex lens L36, the negative meniscus lens L37 that turned the concave surface to reticle 10, a convex lens L38, and reticle 10, a convex The turned positive meniscus lens L39, negative meniscus lens [which turned the concave surface to reticle 10] L3A, It consists of negative meniscus lens L3E which turned the convex to positive meniscus lens L3D and reticle 10 which turned the convex to convex lens L3B, negative meniscus lens L3C which turned the convex to reticle 10, and reticle 10.

[0079] That is, this example consists of one the plane mirror, the lieberkuhn of one sheet, and 19 dioptic lenses which have opening in the center, and, for an image formation scale factor, 0.25 times and numerical aperture are [5mm and the maximum mirror diameter of 0.45 and image quantity] 75mm. However, since this example also serves as optical-character ability almost near non-aberration, it is clear that image quantity can be further enlarged with twice to 3 times by proportion amplification of optical system. Moreover, the 2nd convergence group G2 The configuration of the Mangin mirror of the type with which the dioptic lens and the reflecting mirror were separated is taken

including one negative meniscus lens.

[0080] Although, as for all dioptric lenses, the optical system of this example is also using one kind of optical glass which consists of fused quartzes, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 193nm of ultraviolet rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration also serve as optical system which was excellent in the image formation engine performance amended good.

[0081] The radius of curvature r_i in the 5th example, and spacing d_i And ** material is shown in the following table 5. In the following tables, the 12th page is a virtual side for expressing the lieberkuhn in expansion optical-path drawing.

[0082]

[A table 5]

i	r _i	d _i	material	i	r _i	d _i	material
0	—	2.2		25	148.11	8.0	SiO ₂
1	35.81	8.0	SiO ₂	26	-277.55	2.6	
2	59.46	12.6		27	-68.13	7.5	SiO ₂
3	356.73	6.0	SiO ₂	28	-144.78	0.3	
4	30.20	11.7		29	111.88	11.0	SiO ₂
5	41.51	8.0	SiO ₂	30	-244.49	0.5	
6	-300.87	7.3		31	78.03	11.0	SiO ₂
7	-79.79	6.0	SiO ₂	32	335.30	5.0	
8	-50.60	221.9		33	-89.48	9.0	SiO ₂
9	-110.93	10.0	SiO ₂	34	-178.22	3.0	
10	-226.62	6.0		35	61.88	8.0	SiO ₂
11	-126.76	0.0		36	-734.75	5.0	
12	∞	6.0		37	47.13	6.0	SiO ₂
13	226.62	10.0	SiO ₂	38	22.27	2.0	
14	110.93	119.9		39	26.01	8.5	SiO ₂
15	-31.41	8.0	SiO ₂	40	208.27	3.0	
16	-28.37	1.0		41	18.76	5.0	SiO ₂
17	-76.17	6.0	SiO ₂	42	15.39	11.9	
18	-38.10	1.0					
19	130.38	8.0	SiO ₂				
20	-122.63	1.0					
21	76.08	9.4	SiO ₂				
22	61.43	34.9					
23	172.92	8.0	SiO ₂				
24	-139.74	1.0					

[0083] Moreover, in drawing 16 (a) - (c), longitudinal aberration drawing of the 5th example and drawing 16 (c) show chromatic-aberration-of-magnification drawing of the 5th example, and drawing 16 (e) shows transverse aberration drawing of the 5th

example. These aberration drawing shows that many aberration is amended good in the field of a large image circle, although a numerical aperture is as large as 0.45 also in this example. Moreover, chromatic aberration is also amended good.

[0084] The [6th example] This 6th example is the 1st convergence group G1 while performing cutback projection. And it is the projection optical system which omitted the 2nd convergence group G2. That is, this example corresponds to the optical system of drawing 2. As drawing 17 is expansion optical-path drawing of the projection optical system of the 6th example and it is shown in this drawing 17 The light from the pattern on reticle 10 is 3rd convergence group G3. Plane mirror M3 which passed and was installed in the center at 45 degrees to the optical axis with opening Image formation of the medium image of the pattern is carried out into opening. The light from this 2nd medium image is the lieberkuhn M4. It results in the included 4th convergence group G4, and is the 4th convergence group G4. The reflected light is a plane mirror M3. It is reflected on the outskirts. Thus, the reflected light is the 5th convergence group G5. It passes and image formation of the image of the pattern is carried out to the front face of a wafer 11.

[0085] Moreover, as shown in drawing 17, it is 3rd convergence group G3. Sequentially from reticle 10 To reticle 10, a convex To the turned negative meniscus lens L31 and reticle 10, a convex To the turned negative meniscus lens L32 and reticle 10, a concave surface To the turned negative meniscus lens L33 and reticle 10, a convex The turned negative meniscus lens L34, the positive meniscus lens L35 which turned the concave surface to reticle 10, a convex lens L36, the positive meniscus lens L37 which turned the concave surface to reticle 10, a convex lens L38, the positive meniscus lens L39 which turned the concave surface to reticle 10, convex lens L3A, It consists of convex lens L3B, negative meniscus lens L3C which turned the concave surface to reticle 10, negative meniscus lens L3D which turned the convex to reticle 10, concave lens L3E, convex lens L3F, and convex lens L3G.

[0086] and the 4th convergence group G4 The negative meniscus lens L41 and lieberkuhn M4 which turned the concave surface to reticle 10 the becoming Mangin mirror -- it is -- the 5th convergence group G5 To reticle 10, a convex To the turned positive meniscus lens L51 and reticle 10, a convex It consists of negative meniscus lenses L55 which turned the convex to the turned negative meniscus lens L52, the positive meniscus lens L53 which turned the convex to reticle 10, the positive meniscus lens L54 which turned the concave surface to reticle 10, and reticle 10.

[0087] That is, this example consists of one the plane mirror, the lieberkuhn of one sheet, and 22 dioptic lenses which have opening in the center, and, for an image formation

scale factor, 0.25 times and numerical aperture are [3mm and the maximum mirror diameter of 0.3 and image quantity] 41mm. However, since this example also serves as optical-character ability almost near non-aberration, it is clear that image quantity can be further enlarged with twice to 3 times by proportion amplification of optical system. Moreover, the 4th convergence group G4 The configuration of the Mangin mirror of the type with which the dioptric lens and the reflecting mirror were separated is taken including one negative meniscus lens.

[0088] Although, as for all dioptric lenses, the optical system of this example is also using one kind of optical glass which consists of fused quartzes, the achromatism on a shaft and besides a shaft is made to wavelength width of face of 1nm in the wavelength of 193nm of ultraviolet-rays excimer laser light. Moreover, spherical aberration, comatic aberration, astigmatism, and distortion aberration also serve as optical system which was excellent in the image formation engine performance amended good.

[0089] The radius of curvature r_i in the 6th example, and spacing d_i And ** material is shown in the following table 6. In the following tables, the 35th page is a virtual side for expressing the lieberkuhn in expansion optical-path drawing.

[0090]

[A table 6]

i	r ₁	d ₁	material	i	r ₁	d ₁	material
0	—	4.0		25	48.77	10.0	SiO ₂
1	95.98	10.0	SiO ₂	26	43.54	5.0	
2	65.75	12.0		27	-112.55	4.0	SiO ₂
3	1434.55	7.0	SiO ₂	28	21.60	1.5	
4	60.07	11.0		29	204.26	12.0	SiO ₂
5	-23.22	10.0	SiO ₂	30	-34.05	0.3	
6	-27.51	0.3		31	24.14	7.5	SiO ₂
7	251.93	8.0	SiO ₂	32	-42.62	140.0	
8	51.85	8.0		33	-131.63	10.5	SiO ₂
9	-68.40	7.0	SiO ₂	34	-280.63	5.2	
10	-66.60	51.0		35	∞	0.0	
11	763.14	15.0	SiO ₂	36	143.16	5.2	
12	-105.25	2.0		37	280.63	10.5	SiO ₂
13	-2171.46	11.0	SiO ₂	38	131.63	175.6	
14	-398.28	0.6		39	99.65	8.0	SiO ₂
15	657.88	15.0	SiO ₂	40	856.91	0.5	
16	-195.65	65.0		41	34.40	8.0	SiO ₂
17	-1397.29	14.0	SiO ₂	42	28.44	7.0	
18	-159.18	8.0		43	44.86	7.5	SiO ₂
19	238.03	11.0	SiO ₂	44	115.52	5.0	
20	-292.91	0.5		45	-79.28	7.0	SiO ₂
21	90.28	11.2	SiO ₂	46	-66.11	0.5	
22	-713.33	4.0		47	22.09	8.0	SiO ₂
23	-101.29	9.0	SiO ₂	48	18.08	11.9	
24	-216.96	0.3					

[0091] Moreover, in drawing 18 (a) - (c), longitudinal aberration drawing of the 6th example and drawing 18 (c) show chromatic-aberration-of-magnification drawing of the 6th example, and drawing 18 (e) shows transverse aberration drawing of the 6th

example. Also in this example, a numerical aperture is 0.3, and these aberration drawing shows that many aberration is amended good in the field of an image circle. Moreover, chromatic aberration is also amended good.

[0092] Next, although it is made desirable to be satisfied with this invention of the conditions of a (1) type - (4) type, it explains per [of each above-mentioned examples and those conditions] response below. First, the 1st convergence group G1 - the 5th convergence group G5 in each above-mentioned example The refractive index of n_i ($i=1-5$) and each appearance is set to n_i ($i=1-5$), and each image formation scale factor is set [each focal distance] to β_{aij} ($i=1-5$) for f_i ($i=1-5$) and each PETTSU bar sum. Moreover, the 2nd convergence group G2 The 1st inner lieberkuhn M2 And the 2nd lieberkuhn M4 in the 4th convergence group G4 Radius of curvature, respectively as R_i ($i=1-4$) The 1st convergence group G1 And the 2nd convergence group G2 They are beta12 and the 4th convergence group G4 about a composite image formation scale factor. And the 5th convergence group G5 These image formation scale factors beta12 and beta45 are expressed with β_{aij} , using a composite image formation scale factor as beta45. The item of the 1st above-mentioned example - the 6th example is summarized in the following table 7 - a table 12, respectively. However, it is GT about the whole system. It expresses and is the whole system GT. It is β_{aij} about the corresponding PETTSU bar sum n_i and an image formation scale factor. The PETTSU bar sum and the image formation scale factor of the whole system are shown in a column, respectively.

[0093]

[A table 7]

Item of the 1st embodiment

	R_i	f_i	p_i	n_i	β_i	β_{ij}
G ₁	—	145.01	0.00436	1.581705	1.33	-1.17
G ₂	-1190	594.96	-0.00168	-1.000000	-0.876	
G ₃	—	146.71	-0.00548	-1.243795	-1.00	-1.00
G ₄	-1190	594.96	-0.00168	-1.000000	-1.14	-0.85
G ₅	—	145.01	0.00436	1.581705	0.75	
G _T	—	—	-0.0001	—	-1.00	-1.00

[0094]

[A table 8]

Item of the 2nd embodiment

	R_i	f_i	p_i	n_i	β_i	β_{ij}
G_1	—	70.19	0.00960	1.483971	1.70	-1.12
G_2	-158	95.26	-0.01485	-0.70688	-0.66	
G_3	—	114.70	0.01008	0.86487	-1.00	-1.00
G_4	-158	95.26	-0.01485	-0.70688	-1.52	-0.90
G_5	—	70.19	0.00960	1.483971	0.59	
G_T	—	—	-0.0004	—	-1.01	-1.01

[0095]

[A table 9]

Item of the 3rd embodiment

	R_i	f_i	p_i	n_i	β_i	β_{ij}
G_1	—	-793.98	-0.00196	0.642	0.826	-0.412
G_2	-186	103.76	-0.01254	-0.768	-0.4988	
G_3	—	104.63	0.01688	0.566	-0.7755	-0.7755
G_4	-167	102.82	-0.01491	-0.653	-2.425	-0.7828
G_5	—	52.26	0.01294	1.483	0.3228	
G_T	—	—	0.00040	—	-0.25	-0.25

[0096]

[A table 10]

Item of the 4th embodiment

\backslash	R_i	f_i	p_i	n_i	β_i	β_{ij}
G_1	—	508.51	0.00216	0.91045	35.70	-0.645
G_2	-428	333.45	-0.00592	-0.50658	-0.0181	
G_3	—	—	—	—	—	—
G_4	-417	328.19	-0.00609	-0.5003	-10.836	-0.313
G_5	—	100.04	0.00983	1.01689	0.029	
G_T	—	—	-0.00003	—	0.20	-0.20

[0097]

[A table 11]

Item of the 5th embodiment

\backslash	R_i	f_i	p_i	n_i	β_i	β_{ij}
G_1	—	-132.32	-0.00865	0.8737	0.5585	-0.254
G_2	-127	82.86	-0.01909	-0.6322	-0.455	
G_3	—	144.58	0.02795	0.2475	-0.9837	-0.9837
G_4	—	—	—	—	—	—
G_5	—	—	—	—	—	—
G_T	—	—	0.00058	—	0.25	0.25

[0098]

[A table 12]

Item of the 6th embodiment

\backslash	R_i	f_i	p_i	n_i	β_i	β_{ij}
G_1	—	—	—	—	—	—
G_2	—	—	—	—	—	
G_3	—	25.004	0.01409	2.8384	-0.2847	-0.2847
G_4	-143	94.979	-0.01687	-0.6241	-2.2162	-0.8783
G_5	—	84.227	0.00306	3.87995	0.3963	
G_T	—	—	0.00028	—	0.25	0.25

[0099] Next, based on the above-mentioned table 7 - a table 12, it is collectively shown in the following table what kind of value the value of the parameter of conditional expression (1) - (4) is in each example.

[0100]

[A table 13]

[0099] Next, based on the above-mentioned table 7 - a table 12, it is collectively shown in the following table what kind of value the value of the parameter of conditional expression (1) - (4) is in each example.

[0100]

[A table 13]

Value of the parameter of conditional expression (1)-(4)

条件式	実施例	1	2	3	4	5	6
(1) $p_1 + p_3 + p_5 > 0$	0.00324	0.02928	0.02786	0.01199	0.0193	0.017	
(1) $p_2 + p_4 < 0$	-0.00336	-0.02970	-0.02745	-0.01201	-0.0191	-0.017	
(2) $0.1 \leq \beta_{12} \leq 2$	1.17	1.12	0.4	0.65	0.25	—	
(3) $0.1 \leq \beta_3 \leq 2$	1.0	1.0	0.77	—	0.98	0.28	
(4) $0.1 \leq \beta_{45} \leq 2$	0.85	0.9	0.78	0.31	—	0.88	

[0101] Moreover, the 2nd convergence group G2 which appears in these conditional expression (9) and (10) although it is made desirable to be also satisfied with this invention of conditional expression (9) and (10) And the 4th convergence group G4 Each parameters R2, p2, n2, R4, p4, and n4 It is shown in the following table what kind of value the value is in each example.

[0102]

[A table 14]

Value of the parameter of conditional expression (9), (10)

諸量 実施例	R ₂	p ₂	n ₂	R ₄	p ₄	n ₄
1	1190.	-0.00168	-1.0	1190.	-0.00168	-1.0
2	158.	-0.01485	-0.70688	158.	-0.01485	-0.70688
3	186.	-0.01254	-0.768	167.	-0.01491	-0.653
4	428.	-0.00592	-0.50658	417.	-0.00609	-0.5003
5	127.	-0.01909	-0.6322	—	—	—
6	—	—	—	143.	-0.01687	-0.6241

[0103] Moreover, in each example, amount of many n₂p₂ or 2/| R₂ | of conditional expression (9) and (10) and n₄p₄ or 2/| R₄ | are as follows from a table 14, respectively.

[0104]

[A table 15]

Value of the parameter of conditional expression (9), (10)

諸量 実施例	n ₂ p ₂	2/ R ₂	n ₄ p ₄	2/ R ₄
1	0.00168	0.00168	0.00168	0.00168
2	0.0104971	0.0126574	0.0104971	0.0126574
3	0.0096307	0.0107503	0.0097362	0.0107503
4	0.0029989	0.0046782	0.0030468	0.0048009
5	0.0120686	0.0157778	—	—
6	—	—	0.0105285	0.0139703

[0105] As for each of these tables, in each above-mentioned example, all show that the conditions of a (1) type - (4) type and the conditions of (9) types and (10) types are satisfied. In addition, in each above-mentioned example, although optical glass, such as a quartz and fluorite, is used as ** material which constitutes dioptric system, since optical glass, such as a quartz and fluorite, can let ultraviolet rays pass, it is convenient.

[0106] However, when the illumination light to be used is infrared radiation, optical glass, such as silicon (Si), germanium (germanium), zinc sulfide (ZnS), or a zinc selenide (ZnSe), can also be used as ** material which constitutes dioptric system. These ** material is because the permeability to infrared radiation is large. Moreover, you may make it use plastics optical material, such as an acrylic, polystyrene, and a

polycarbonate, as an ingredient which constitutes dioptric system. Thereby, the optical system of low cost with mass production nature is realizable.

[0107] Furthermore, this invention is also applicable to the so-called common image pick-up lens which carries out image formation of the image of the body of infinite distance distance on a predetermined observation side instead of the reticle 10 in the distance of finite. Moreover, it is also possible to apply to the aligner for the so-called scanning exposure which projects an axial outer ring of spiral-wound-gasket band-like body for the optical system of each above-mentioned example only using an axial outdoor daylight bundle, and is exposed while moving reticle 10 and a wafer 11 at a different rate corresponding to the scale factor of a projection optical system. Thereby, a projection optical system can be miniaturized.

[0108] Moreover, although the above-mentioned example is an example of actual size or a cutback projection optical system, use [it / as an amplification projection optical system] is clear by making relation between reticle 10 and a wafer 11 into reverse. As an application of such amplification optical system, an ultraviolet ray microscope etc. is leading. Thus, this invention is not limited to the above-mentioned example, but can take configurations various in the range which does not deviate from the summary of this invention.

[0109]

[Effect of the Invention] According to the 1st reflective refraction projection optical system of this invention, while bending the optical path of the flux of light according to selection optical system, image formation of the medium image was carried out near the optical axis of the selection optical system by the flux of light from the lieberkuhn, or the light from the medium image near the optical axis of the selection optical system is led to the lieberkuhn. Therefore, the PETTSU bar sum and axial overtone aberration can be amended good. Moreover, combination with a part of dioptric system can also amend distortion aberration and the chromatic aberration of magnification common to unsymmetrical optical system to fitness, and they can also amend spherical aberration and comatic aberration good. Therefore, there is an advantage which can offer the reflective refraction projection optical system which was excellent in the image formation engine performance which can take an one-shot exposure method, without using a beam splitter.

[0110] Moreover, while according to the 2nd reflective refraction projection optical system of this invention there is no need of using a beam splitter and the image formation engine performance is excellent, an one-shot exposure method can be taken. Furthermore, there is an advantage which can enlarge the radius of curvature of each

lieberkuhn and can make aberration small by using the lieberkuhn of two sheets. Moreover, according to the 3rd reflective refraction projection optical system of this invention, while the image formation engine performance is excellent not using the beam splitter, an one-shot exposure method can be taken. Furthermore, there is an advantage which can enlarge the radius of curvature of each lieberkuhn and can make aberration small by using the lieberkuhn of two sheets. Furthermore, since the 3rd convergence group is prepared between the 1st selection optical system and the 2nd selection optical system, there is an advantage which can control an image formation scale factor and many aberration in the large range.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is the block diagram showing the 1st basic configuration of the reflective refraction projection optical system by this invention.

[Drawing 2] It is the block diagram showing the modification of the basic configuration of drawing 1.

[Drawing 3] It is the block diagram showing the 2nd basic configuration of the reflective refraction projection optical system by this invention.

[Drawing 4] It is the block diagram showing the 3rd basic configuration of the reflective refraction projection optical system by this invention.

[Drawing 5] It is the block diagram showing the modification of the basic configuration of drawing 4.

[Drawing 6] It is expansion optical-path drawing showing the projection optical system of the 1st example of this invention.

[Drawing 7] The 1st convergence group G1 in the 1st example It is optical-path drawing showing a detailed configuration.

[Drawing 8] It is aberration drawing of the 1st example.

[Drawing 9] It is expansion optical-path drawing showing the projection optical system of the 2nd example of this invention.

[Drawing 10] It is aberration drawing of the 2nd example.

[Drawing 11] It is expansion optical-path drawing showing the projection optical system of the 3rd example of this invention.

[Drawing 12] It is aberration drawing of the 3rd example.

[Drawing 13] It is expansion optical-path drawing showing the projection optical system

of the 4th example of this invention.

[Drawing 14] It is aberration drawing of the 4th example.

[Drawing 15] It is expansion optical-path drawing showing the projection optical system of the 5th example of this invention.

[Drawing 16] It is aberration drawing of the 5th example.

[Drawing 17] It is expansion optical-path drawing showing the projection optical system of the 6th example of this invention.

[Drawing 18] It is aberration drawing of the 6th example.

[Description of Notations]

1 Body Side

2 Image Surface

10 Reticle

11 Wafer

G1 The 1st convergence group

G2 The 2nd convergence group

G3 The 3rd convergence group

G4 The 4th convergence group

G5 The 5th convergence group

M1, M3 Plane mirror which has opening

H1, H2 Opening

M2, M4 Lieberkuhn

M1' and M3' minute plane mirror

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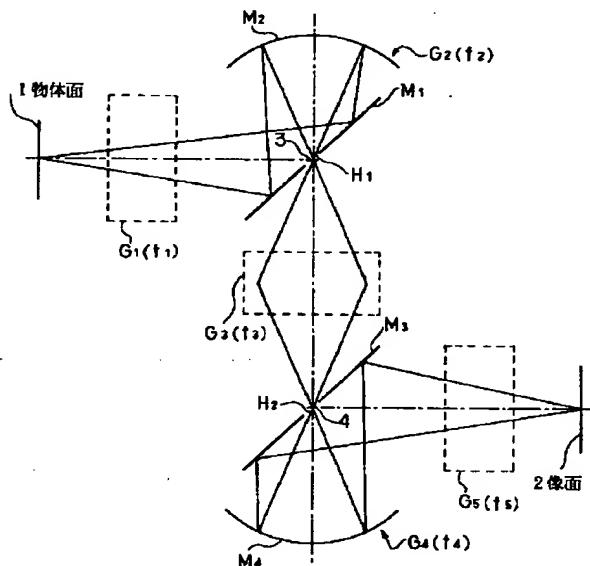
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(54)【発明の名称】 反射屈折投影光学系

(57)【要約】

【目的】 ビームスプリッターを用いること無く、且つ一括露光方式を取ることが出来る結像性能の優れた反射屈折投影光学系を提供する。

【構成】 物体面1上のパターンからの光が、第1収斂群G₁を経て、第1平面鏡M₁の周辺部で反射された後、第1凹面反射鏡M₂よりなる第2収斂群G₂に至り、第2収斂群G₂で反射された光が第1平面鏡M₁の開口内にそのパターンの第1中間像を結像する。この第1中間像からの光が、第3収斂群G₃を経て、第2平面鏡M₂の開口内にそのパターンの第2中間像を結像し、この第2中間像からの光が第2凹面反射鏡M₃よりなる第4収斂群G₄に至り、第4収斂群G₄で反射された光が第2平面鏡M₃の周辺で反射され、この反射光が、第5収斂群G₅を経て像面2の表面にそのパターンの第3中間像を結像する。



【特許請求の範囲】

【請求項1】 第1面上のパターンの像を第2面上に投影する光学系であって、前記第1面上のパターンの中間像を結像する第1部分結像光学系と、前記中間像の像を前記第2面上に再結像する第2部分結像光学系とを配置し、前記2つの部分結像光学系の少なくとも一方の部分結像光学系は、第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射すると共に前記第1の領域又は第2の領域に前記中間像が結像される選択光学系と、該選択光学系を介して導かれた光束を再び該選択光学系に戻す凹面反射鏡と、前記第1面と前記選択光学系との間又は前記選択光学系と前記第2面との間に配置された収斂群とを有することを特徴とする反射屈折投影光学系。

【請求項2】 第1面上のパターンの像を第2面上に投影する光学系であって、前記第1面上のパターンの中間像を結像する第1部分結像光学系と、前記中間像の像を前記第2面上に結像する第2部分結像光学系とを配置し、前記第1部分結像光学系は、光軸に対して斜めに配置され第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射する選択光学系と、前記第1面上のパターンからの光束を前記選択光学系に導く第1収斂群と、前記選択光学系で反射された光束を反射して前記選択光学系の前記第1の領域又は前記第2の領域内に前記パターンの中間像を結像する第1凹面反射鏡とを有し、前記第2部分結像光学系は、前記選択光学系内の前記中間像からの光束を再び前記選択光学系に戻す第2凹面反射鏡と、前記選択光学系で再び反射された光束より前記中間像の像を前記第2面上に結像する第2収斂群とを有することを特徴とする反射屈折投影光学系。

【請求項3】 第1面上のパターンの像を第2面上に投影する光学系であって、前記第1面より順に、前記第1面上のパターンからの光束を収斂する焦点距離 f_1 の第1収斂群と、第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射し、前記第1収斂群からの光束を後続の光学系に導く第1選択光学系と、第1凹面反射鏡を含み、前記第1選択光学系からの光束を反射して前記第1選択光学系の前記第1の領域又は前記第2の領域内に前記パターンの第1中間像を結像する焦点距離 f_2 の第2収斂群と、前記第1中間像からの光束を収斂して前記パターンの第2中間像を結像する焦点距離 f_3 の第3収斂群と、第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射すると共に、該第1の領域又は該第2の領域内に前記第2中間像が結像される第2選択光学系と、

第2凹面反射鏡を含み、前記第2中間像からの光束を前記第2選択光学系に戻す焦点距離 f_4 の第4収斂群と、前記第2選択光学系により導かれた光束を収斂して、前記第2面上に前記パターンの第3中間像を結像する焦点距離 f_5 の第5収斂群と、を有することを特徴とする反射屈折投影光学系。

【請求項4】 前記第1選択光学系及び前記第2選択光学系は、それぞれ所定形状の開口を有し、該開口内にそれぞれ前記パターンの中間像が結像される反射鏡であることを特徴とする請求項3記載の反射屈折投影光学系。

【請求項5】 前記第1選択光学系及び前記第2選択光学系は、それぞれ所定形状の反射部を有し、該反射部内にそれぞれ前記パターンの中間像が結像される小型反射鏡であることを特徴とする請求項3記載の反射屈折投影光学系。

【請求項6】 前記第1収斂群～前記第5収斂群の個別のペツツバール和をそれぞれ $p_1 \sim p_5$ としたとき、 $p_1 + p_2 + p_3 > 0$ 且つ $p_2 + p_4 < 0$ の条件を満足することを特徴とする請求項3、4又は5記載の反射屈折投影光学系。

【請求項7】 前記第1収斂群及び第2収斂群による前記第1中間像の結像倍率を β_{12} としたとき、 $0.1 \leq |\beta_{12}| \leq 2$ の条件を満足することを特徴とする請求項3、4、5又は6記載の反射屈折投影光学系。

【請求項8】 前記第3収斂群による前記第1中間像から前記第2中間像への結像倍率を β_3 としたとき、 $0.1 \leq |\beta_3| \leq 2$ の条件を満足することを特徴とする請求項3～7記載の反射屈折投影光学系。

【請求項9】 前記第4収斂群及び第5収斂群による前記第2中間像から前記第3中間像への結像倍率を β_{45} としたとき、 $0.1 \leq |\beta_{45}| \leq 2$ の条件を満足することを特徴とする請求項3～8記載の反射屈折投影光学系。

【請求項10】 前記第1選択光学系内で前記第1中間像が結像される領域の周辺部と前記第3収斂群の瞳面とを共役の関係に設定し、前記第3収斂群の瞳面と前記第2選択光学系内で前記第2中間像が結像される領域の周辺部とを共役の関係に設定したことを特徴とする請求項3～9記載の反射屈折投影光学系。

【請求項11】 前記第1収斂群の後側主点と前記第1選択光学系内で前記第1中間像が結像される位置との間隔を前記第1収斂群の焦点距離 f_1 とほぼ等しく設定し、前記第1面側でほぼテレセントリック光学系となるようにしたことを特徴とする請求項3～10記載の反射屈折投影光学系。

【請求項12】 前記第5収斂群の前側主点と前記第2選択光学系内で前記第2中間像が結像される位置との間

隔を前記第5収斂群の焦点距離 f_5 とほぼ等しく設定し、前記第2面側でほぼテレセントリック光学系となるようにしたことを特徴とする請求項3～11記載の反射屈折投影光学系。

【請求項13】前記第1収斂群の後側主点と前記第1選択光学系内で前記第1中間像が結像される位置との間隔を前記第1収斂群の焦点距離 f_1 とほぼ等しく設定し、前記第5収斂群の前側主点と前記第2選択光学系内で前記第2中間像が結像される位置との間隔を前記第5収斂群の焦点距離 f_5 とほぼ等しく設定し、前記第1面側及び前記第2面側でそれぞれほぼテレセントリック光学系となるようにしたことを特徴とする請求項3～12記載の反射屈折投影光学系。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、例えば半導体素子又は液晶表示素子等をフォトリソグラフィ工程で製造する際に使用される投影露光装置の、等倍又は縮小投影用の投影光学系に適用して好適な反射屈折投影光学系に関し、特に、光学系の要素として反射系を用いることにより、紫外線波長域でサブミクロン単位の解像度を有する反射屈折投影光学系に関する。

【0002】

【従来の技術】半導体素子又は液晶表示素子等をフォトリソグラフィ工程で製造する際に、フォトマスク又はレチカル（以下、「レチカル」と総称する）のパターン像を投影光学系を介して例えば1/5程度に縮小して、感光材（フォトレジスト等）が塗布された基板（ウエハ、ガラスプレート等）上に露光する投影露光装置が使用されている。半導体素子等の集積度が向上するにつれて、投影露光装置に使用されている投影光学系に要求される解像力は益々高まっている。

【0003】この要求を満足するためには、照明光の波長を短波長化し且つ投影光学系の開口数（NA）を大きくしなければならない。しかしながら、照明光の波長が短くなると、光の吸収のため実用に耐える硝材の種類が限られてくる。特に、波長が300nm以下になると実用上使える硝材は合成石英と萤石だけとなる。両者のアッペ数は色収差を補正するのに十分な程離れていないので、波長が300nm以下になった場合には、屈折系だけで投影光学系を構成したのでは色収差補正が極めて困難となる。また、萤石は温度変化による屈折率の変化特性、所謂温度特性が悪く、更にレンズ研磨の加工上で多くの問題を持っているため、萤石を多くの部分に使用することはできない。従って、要求される解像力を有する投影光学系を屈折系のみで形成することは非常に難しい。

【0004】これに対して反射系は色収差が無いため、反射系のみで投影光学系を構成することも試みられているが、この場合、投影光学系が大型化し、且つ反射面の

非球面化が必要となる。即ち、反射系のみで投影光学系を構成することも極めて困難である。そこで、反射系と屈折系とを組み合わせた所謂反射屈折光学系で縮小投影光学系を構成する技術が種々提案されている。その一例として例えば特開昭63-163319号公報では、リング視野光学系が提案されている。このリング視野光学系では、入射光と反射光とが互いに干渉しないように軸外光を用い、且つ軸外の輪帯部のみを露光するように構成されている。

【0005】また、別の例として、例えば特公昭51-27116号公報や特開平2-66510号公報において、内部に半透鏡で構成されるビームスプリッターを配置することにより、軸上付近の光束を使って一括してレチカルの像を投影する反射屈折光学系を備えた縮小投影型露光装置が提案されている。

【0006】

【発明が解決しようとする課題】上記の如き従来の技術の内で、リング視野光学系では、入射光と反射光との干渉を避けるため、多くのミラーを使って光束を何回も反射させることが必要であり、そのため全体の光学系が複雑になると共に、開口数を大きくすることが困難であるという不都合がある。

【0007】しかも、露光エリアが狭くレチカルのパターンを一括で例えばウエハ上に露光することも出来ないので、レチカルとウエハとを投影光学系の縮小倍率に応じて互いに異なる速度で移動しながら露光する、所謂スキャン露光を行う必要があった。このため、投影露光装置の機構部の構成が複雑となり、製造コスト及び露光精度の点で不利であった。即ち、スキャン露光方式では、超微細パターンをウエハ上に高精度に露光するのが困難であり、製造コストも非常に高いものとならざるを得なかった。

【0008】一方、軸上付近の光束を使って一括してレチカルの像を投影する従来の反射屈折光学系では、ウエハ面からの反射光による内面反射や、ビームスプリッター以降の光学系の屈折面での内面反射によるフレアが多いという不都合があった。更に、光束の入射角度の変化によるビームスプリッターの反射特性の不均一性、反射膜による光の吸収、反射膜における光の位相変化、及び反射膜自体の不均一性等が結像特性を劣化させるという不都合があり、投影光学系としての総合的な解像力が劣化し、特に半導体製造用露光装置の投影光学系としては解像力が十分では無かった。また、ビームスプリッターによる光量損失のため、光の利用効率が25%～10%程度の低いものとなり、実用的とは言えなかった。

【0009】本発明は斯かる点に鑑み、半透鏡で構成されるビームスプリッターを用いることなく、反射系と屈折系とを用いて構成され、且つ軸外光束を用いて輪帯部のみを露光するリング視野光学系とは異なり一括露光方式を取ることが出来る、結像性能の優れた反射屈折投影

光学系を提供することを目的とする。

【0010】

【課題を解決するための手段】本発明による第1の反射屈折投影光学系は、例えば図1に示すように、第1面

(1) 上のパターンの像を第2面(2)上に投影する光学系であって、第1面(1)上のパターンの中間像

(3) を結像する第1部分結像光学系と、中間像(3)の像を第2面(2)上に再結像する第2部分結像光学系とを配置し、それら2つの部分結像光学系の少なくとも一方の部分結像光学系は、第1の領域の光を通過させてこの第1の領域とは異なる第2の領域の光を反射すると共にそれら第1の領域又は第2の領域に中間像(3)が結像される選択光学系M₁と、この選択光学系を介して導かれた光束を再びこの選択光学系に戻す凹面反射鏡M₂と、第1面(1)と選択光学系M₁との間又は選択光学系M₁と第2面(2)との間に配置された収斂群G₁とを有するものである。

【0011】なお、図1の光学系は第1部分結像光学系が凹面反射鏡M₂を有する例であるが、第2部分結像光学系が凹面反射鏡M₄を有する例が図2の光学系である。即ち、図1の光学系及び図2の光学系は共に、本発明の第1の反射屈折投影光学系に属する。

【0012】また、第2の反射屈折投影光学系は、例えば図3に示すように、第1面(1)上のパターンの像を第2面(2)上に投影する光学系であって、第1面

(1) 上のパターンの中間像(3)を結像する第1部分結像光学系と、中間像(3)の像を第2面(2)上に結像する第2部分結像光学系とを配置し、その第1部分結像光学系は、光軸に対して斜めに配置され第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射する選択光学系M₁と、第1面(1)上のパターンからの光束を選択光学系M₁に導く第1収斂群G₁と、選択光学系M₁で反射された光束を反射して選択光学系M₁のその第1の領域又はその第2の領域内にそのパターンの中間像(3)を結像する第1凹面反射鏡M₂とを有し、その第2部分結像光学系は、選択光学系M₁内の中間像(3)からの光束を再び選択光学系M₁に戻す第2凹面反射鏡M₄と、選択光学系M₁で再び反射された光束より中間像(3)の像を第2面(2)上に結像する第2収斂群G₂とを有するものである。

【0013】また、第3の反射屈折投影光学系は、例えば図4に示すように、第1面(1)上のパターンの像を第2面(2)上に投影する光学系であって、第1面

(1)より順に、第1面(1)上のパターンからの光束を収斂する焦点距離f₁の第1収斂群G₁と、第1の領域の光を通過させて該第1の領域とは異なる第2の領域
 $p_1 + p_2 + p_3 > 0$ 且つ $p_1 + p_4 < 0$

【0018】また、第1収斂群G₁及び第2収斂群G₂による第1中間像(3)の結像倍率をβ₁₂、全系の結像倍率をβとしたとき、次の条件を満足することが望まし

の光を反射し、第1収斂群G₁からの光束を後続の光学系に導く第1選択光学系M₁と、第1凹面反射鏡M₂を含み、第1選択光学系M₁からの光束を反射して第1選択光学系M₁のその第1の領域又はその第2の領域内にそのパターンの第1中間像(3)を結像する焦点距離f₁の第2収斂群G₂と、第1中間像(3)からの光束を収斂してそのパターンの第2中間像(4)を結像する焦点距離f₂の第3収斂群G₃と、第1の領域の光を通過させて該第1の領域とは異なる第2の領域の光を反射すると共に、該第1の領域又は該第2の領域内に第2中間像(4)が結像される第2選択光学系M₂と、第2凹面反射鏡M₄を含み、第2中間像(4)からの光束を第2選択光学系M₂に戻す焦点距離f₃の第4収斂群G₄と、第2選択光学系M₂により導かれた光束を収斂して、第2面(2)上にそのパターンの第3中間像を結像する焦点距離f₄の第5収斂群G₅と、を有するものである。

【0014】この場合、その第1選択光学系及びその第2選択光学系の一例は、例えば図4に示すように、それぞれ所定形状の開口(H₁、H₂)を有し、これら開口内にそれぞれそのパターンの中間像(3、4)が結像される反射鏡(M₁、M₂)である。

【0015】また、その第1選択光学系及びその第2選択光学系の他の例は、例えば図5に示すように、それぞれ所定形状の反射部を有し、これら反射部内にそれぞれそのパターンの中間像(3、4)が結像される小型反射鏡(M₁、M₂)である。従って、図4の光学系と図5の光学系とは光学的に等価である。

【0016】この場合、図1の光学系は図4の光学系から、第2選択光学系M₂～第5収斂群G₅を省いたものと等価であり、図2の光学系は図4の光学系から、第1収斂群G₁～第1選択光学系M₁を省いたものと等価である。また、図3の光学系は図4の光学系から第3収斂群G₃を省いたものと等価である。従って、本発明による第1及び第2の反射屈折投影光学系は、それぞれ本発明による第3の反射屈折投影光学系から、収斂群G₁～G₅及び選択光学系M₁、M₂の中の何れかの要素を省いたものと考えることができる。そして、このように省かれた収斂群G₁～G₅のペツツバール和を0とみなすことにより、以下の条件式(1)～(10)において本発明の第3の反射屈折投影光学系に対して課している条件は、それぞれ本発明の第1及び第2の反射屈折投影光学系にも適用されるものである。

【0017】即ち、先ず、第1収斂群G₁～第5収斂群G₅の個別のペツツバール和をそれぞれp₁～p₅としたとき、次の条件を満足することが望ましい。

(1)

い。

$$0.1 \leq |\beta_{12}| \leq 2 \quad (2)$$

また、第3収斂群G₅による第1中間像(3)から第2

中間像(4)への結像倍率を β_4 としたとき、次の条件を満足することが望ましい。

【0019】

$$0.1 \leq |\beta_4| \leq 2 \quad (3)$$

【0020】更に、第4収斂群 G_4 及び第5収斂群 G_5 による第2中間像(3)から第3中間像(4)への結像倍率を β_{45} としたとき、次の条件を満足することが望ましい。

$$0.1 \leq |\beta_{45}| \leq 2 \quad (4)$$

また、第1選択光学系 M_1 内で中間像(3)が結像される領域 H_1 の周辺部と第3収斂群 G_3 の瞳面とを共役の関係に設定し、第3収斂群 G_3 の瞳面と第2選択光学系 M_2 内で中間像(4)が結像される領域 H_2 の周辺部とを共役の関係に設定することが望ましい。

【0021】更に、第1収斂群 G_1 の後側主点と第1選択光学系 M_1 内で中間像(3)が結像される位置との間隔を第1収斂群 G_1 の焦点距離 f_1 とほぼ等しく設定し、第1面(1)側でほぼテレセントリック光学系となることが望ましい。また、第5収斂群 G_5 の前側主点と第2選択光学系 M_2 内で中間像(4)が結像される位置との間隔を第5収斂群 G_5 の焦点距離 f_5 とほぼ等しく設定し、第2面(2)側でほぼテレセントリック光学系となることが望ましい。

【0022】また、第1収斂群 G_1 の後側主点と第1選択光学系 M_1 内で中間像(3)が結像される位置との間隔を第1収斂群 G_1 の焦点距離 f_1 とほぼ等しく設定し、第5収斂群 G_5 の前側主点と第2選択光学系 M_2 内で中間像(4)が結像される位置との間隔を第5収斂群 G_5 の焦点距離 f_5 とほぼ等しく設定し、第1面(1)側及び第2面(2)側でそれぞれほぼテレセントリック光学系となることが望ましい。

【0023】

【作用】斯かる本発明の第1の反射屈折投影光学系によれば、第1部分結像光学系による第1面(1)上のパターンの中間像(3)が、第2部分結像光学系により第2面(2)上にリレーされる。また、第1部分結像光学系及び第2部分結像光学系の少なくとも一方に凹面反射鏡 M_1 が使用され、屈折系とその凹面反射鏡 M_1 との間の光路を折り曲げる手段として、中央に開口を有する反射鏡(例えば図1の M_1)又は中央部だけ光を反射する小型反射鏡(例えば図5の M_1')等の選択光学系 M_1 が使用されており、この選択光学系 M_1 の中央部に中間像(3)が結像されている。従って、従来のフレア等の原因になると共に照明光の無駄が多いハーフミラー型のビームスプリッターが使用されていないため、光束の大部分を有効に使うことができる。なお、図1～図5の光学系では、それぞれ第1面(1)は物体面、第2面(2)は像面として表示されている。

【0024】勿論、選択光学系 M_1 の光軸付近の光束は一部けられて結像に寄与しないため、輪帶状の瞳を持つ

光学系となり、そのときの遮蔽率により、結像特性は種々に変化したものとなるという特徴を有する。しかしながら、最近では遮蔽部のない通常の屈折光学系を投影光学系として使用する投影露光装置においても、わざわざ照明光学系の光軸付近の光を遮蔽して解像力を上げる所謂変形光源法が提案されているくらいであり、結像特性の変化による像の変化は感光材の特性やレチクルの設計により補うことが出来るものである。

【0025】それよりも、トータルの光量損失がハーフミラーを使用するものに比べて少ないと共に、一括露光が出来て複雑なスキャン露光を必要としないという利点の方が大きい。また、本発明の第2の反射屈折投影光学系によれば、例えば図3に示すように、第1凹面反射鏡 M_1 を有する第1部分結像光学系による第1面(1)上のパターンの中間像(3)が、選択光学系 M_2 の光軸近傍に結像され、この中間像(3)が第2凹面反射鏡 M_4 を有する第2部分結像光学系により第2面(2)上にリレーされる。従って、ハーフミラー型のビームスプリッターが使用されていないため、光束の大部分を有効に使うことができる。更に、凹面反射鏡(M_2, M_4)が2個使用されているため、個々の凹面反射鏡の曲率半径を、凹面反射鏡が1個使用されている場合に比べて2倍にすることができ、諸収差が低減する。

【0026】また、本発明の第3の反射屈折投影光学系によれば、例えば図4に示すように、第1収斂群 G_1 及び主に第1凹面反射鏡 M_1 で構成される第2収斂群 G_2 による第1面(1)上のパターンの第1中間像(3)が第1選択光学系 M_1 の光軸近傍に結像され、その第1中間像(3)が第3収斂群 G_3 により第2選択光学系 M_3 の光軸近傍に第2中間像(4)としてリレーされ、その第2中間像(4)が主に第2凹面反射鏡 M_4 で構成される第4収斂群 G_4 及び第5収斂群 G_5 により第2面

(2)上にリレーされる。従って、ハーフミラー型のビームスプリッターが使用されていないため、光束の大部分を有効に使うことができると共に、フレア等が減少する。

【0027】また、第1中間像(3)を第2中間像(4)にリレーする第3収斂群 G_3 が設けられているため、投影倍率又は諸収差等の制御範囲が広がる。なお、その第1選択光学系及びその第2選択光学系として、例えば図4に示すように、それぞれ所定形状の開口(H_1, H_2)を有し、これら開口内にそれぞれそのパターンの中間像(3, 4)が結像される反射鏡(M_1, M_2)を使用した場合と、例えば図5に示すように、それぞれ所定形状の反射部を有し、これら反射部内にそれぞれそのパターンの中間像(3, 4)が結像される小型反射鏡(M_1', M_2')を使用した場合とは、光学的に等価である。

【0028】次に、この第3の反射屈折投影光学系において、結像性能を向上、且つ像面をより平坦にするため

には、先ず光学系全体のペツツバール和を0付近にしなければならない。仮にペツツバール和が0付近にないと投影像面は平坦なものとならず、湾曲したものとなる。このため、第1収斂群G₁～第5収斂群G₅の焦点距離をそれぞれf₁, f₂, f₃, f₄及びf₅とし、各群のペツツバール和をそれぞれp₁, p₂, p₃, p₄及びp₅とし、各群のみかけの屈折率（各群の焦点距離をそれら各群のペツツバール和で割った値）をそれぞれn₁, n₂, n₃, n₄及びn₅とすると、次の関係が成立することが望ましい。

【0029】

$$-0.01 < p_1 + p_2 + p_3 + p_4 + p_5 < 0.01 \quad (5)$$

【0030】この式を満足しないと像面は十分に平坦とならず、仮に下限を越えると像面は第1面（1）に対して凹の湾曲をし、仮に上限を越えると像面は第1面

（1）に対し凸の湾曲をする。本発明ではその（5）式の条件を満足するために、全系のペツツバール和を第1の部分和（p₁+p₂+p₃）と第2の部分和（p₄+p₅）とに分け、それぞれの部分和が（1）式の条件で示すように逆符号になるようにしている。

【0031】この場合、それぞれの群のペツツバール和の内のp₁, p₂及びp₃は、それぞれ次のように表される。

$$p_1 = 1 / (f_1 n_1) \quad (6)$$

$$p_2 = 1 / (f_2 n_2) \quad (7)$$

$$p_3 = 1 / (f_3 n_3) \quad (8)$$

【0032】特に、2群及び4群のペツツバール和p₂及びp₄については、次の条件を満たすことが望ましい。

$$0 \leq n_2 p_2 \leq 2 / |R_2| \quad (9)$$

$$0 \leq n_4 p_4 \leq 2 / |R_4| \quad (10)$$

【0033】これら（9）式及び（10）式において、R₂は第2収斂群G₂の一部を構成する第1凹面反射鏡M₂の曲率半径であり、n₂は第2収斂群G₂のみかけの屈折率であり、同様にR₄は第4収斂群G₄の一部を構成する第2凹面反射鏡M₄の曲率半径であり、n₄は第4収斂群G₄のみかけの屈折率である。（9）式及び（10）式において、それぞれ下限を越えると、全系のペツツバール和は正になり過ぎ、上限を越えると負になり過ぎる。

【0034】また、光学系の第1収斂群G₁と第2収斂群G₂による第1次結像の結像倍率をβ₁₂とし、全系の結像倍率をβとすると、（2）式の条件を満足することが望ましく、仮に（2）式の下限を越えると、第1選択光学系M₁上の第1中間像の結像領域H₁を大きく取らなければならなくなり、遮蔽率が増えて、光量の損失が大きくなり、結像性能が悪くなる。仮に（2）式の上限を越えると、第1収斂群G₁と第2収斂群G₂による第1次結像における収差が大きくなり、やはり結像性能が悪くなる。

【0035】また、第3収斂群G₃による第2次結像の結像倍率をβ₃とすると、（3）式の条件を満足することが望ましく、仮に（3）式の下限を越えると、第2選択光学系M₃上の第2中間像の結像領域H₂を大きく取らなければならなくなり、仮に上限を越えると、遮蔽率が増えて、光量の損失量が増えるのみならず、結像性能が悪くなる。仮に（3）式の上限を越えると、第3収斂群G₃による第2次結像における収差が大きくなり、やはり結像性能が悪くなる。

【0036】また、第4収斂群G₄と第5収斂群G₅による第3次結像の結像倍率をβ₄₅とすると、（3）式の条件を満足することが望ましく、仮に（4）式の下限を越えると、第4収斂群G₄と第5収斂群G₅による第3次結像における収差が大きくなり結像性能が悪くなる。仮に（4）式の上限を越えると、第2選択光学系M₃上で第2中間像（4）が結像される領域H₂を大きく取らなければならなくなり、遮蔽率が増えて、光量の損失量が増して、結像性能が悪くなる。

【0037】また、第3収斂群G₃の中にある開口絞りの位置（ここでは実際に光束が絞られることはなく、主光線が光軸と交わる位置を言う）を瞳面sとすれば、第1選択光学系M₁の領域H₁の周辺部から第2収斂群G₂で反射して、再び領域H₁を通りて第3収斂群G₃の中の瞳面sに到達する光路は、物体と像の関係にある。つまり、領域H₁の周辺部と瞳面sとは共役の関係にあることが望ましい。更に、瞳面sから第2選択光学系M₃の領域H₂を経て第4収斂群G₄で反射されて、再び領域H₂の周辺部に到達する光路も、物体と像の関係があり、瞳面sと領域H₂の周辺部とは共役の関係にあることが望ましい。

【0038】また、例えば図3に示すような、第3収斂群G₃が省略された光学系においては、第1選択光学系M₁の領域H₁の周辺部を経て第2収斂群G₂で反射して、再び領域H₁を通り、その後第4収斂群G₄で反射されて、再び領域H₁の周辺部に到達する光路も、物体と像の関係にある。つまり、領域H₁の一方の面の周辺部と領域H₁の他方の面の周辺部とは共役の関係にあることが望ましい。

【0039】また、例えば図1に示すような、第4収斂群G₄及び第5収斂群G₅が省略された光学系においては、第1選択光学系M₁の領域H₁の周辺部を経て第2収斂群G₂で反射された後、再び領域H₁を通り、第3収斂群G₃の中の瞳面sに到達する光路は、物体と像の関係にある。つまり、領域H₁の周辺部と瞳面sとは共役の関係にあることが望ましい。

【0040】また、例えば図2に示すような、第1収斂群G₁及び第2収斂群G₂が省略された光学系においては、第3収斂群G₃の中の瞳面sからでて、第2選択光学系M₃の領域H₂を経て第4収斂群G₄で反射された後、再び領域H₂に到達する光路も、物体と像の関係に

ある。つまり、瞳面 S と領域 H_1 の周辺部とは共役の関係にあることが望ましい。

【0041】仮に以上に述べたような共役関係が崩れると、領域 H_1 又は領域 H_2 による瞳面 S の遮蔽部分が瞳の中央から、像高に対応してずれてくるため、像高によって光学系の結像特性が変化してしまうという不都合が生じる。また、第1面(1)側において、略々テレセントリック光学系であると、照明系の光学系が大きくならず、都合が良い。そして、第2面(2)側において、略々テレセントリック光学系であると、第2面(2)上の感光基板までの距離が多少変化しても、倍率の変化はなく、幾重もの重ね焼きを行っても寸法のずれがなくなり都合が良い。

【0042】更に、第1面(1)側及び第2面(2)側において、それぞれ略々テレセントリック光学系であると、照明光学系が大きくならず、且つ第2面(2)上の感光基板までの距離が多少変化しても、倍率の変化はなく、幾重もの重ね焼きを行っても寸法のずれがなくなり都合が良い。

【0043】

【実施例】以下、本発明による反射屈折投影光学系の種々の実施例につき図面を参照して説明する。本例は、レチクルのパターンの像をフォトレジストが塗布されたウエハ上に所定倍率(等倍を含む)で投影する投影露光装置の投影光学系に本発明を適用したものである。

【0044】以下の実施例ではレンズ配置を例えれば図6に示すように、展開光路図を表す。展開光路図においては、反射面は透過面として表され、レチクル10からの光が通過する順に各光学要素が配列される。また、凹面反射鏡の部分(例えば r_{10})では、平面の仮想面(例えば r_{10})が使用される。そして、レンズの形状及び間隔を表すために、例えれば図6に示すように、レチクル10のパターン面を第0面として、レチクル10から射出された光がウエハ11に達するまでに通過する面を順次第i面($i=1, 2, \dots$)として、第i面の曲率半径 r_i の符号は、展開光路図の中でレチクル10に対して凸の場合を正にとる。また、第i面と第(i+1)面との面間隔を d_i とする。また、硝材として、CaF₂は萤石、SiO₂は石英ガラスをそれぞれ表す。石英ガラス及び萤石の使用基準波長(248nm)に対する屈折率は次のとおりである。

石英ガラス: 1.508327

萤石: 1.467845

【0045】また、使用基準波長が193nmでは石英ガラスの屈折率は次のようになる。

石英ガラス: 1.56100

【0046】【第1実施例】この第1実施例は等倍の投影光学系である。この第1実施例から以下の第3実施例

までは、図4の光学系に対応する実施例である。図6は第1実施例の投影光学系の展開光路図であり、この図6に示すように、レチクル10上のパターンからの光が、第1収斂群 G_1 を経て、中央に開口を持ち光軸に対して45°で斜設された第1平面鏡 M_1 の周辺部で反射された後、第1凹面反射鏡 M_1 よりなる第2収斂群 G_2 に至り、第2収斂群 G_2 で反射された光が第1平面鏡 M_1 の開口内にそのパターンの第1中間像を結像する。そして、この第1中間像からの光が、凹面反射鏡 M_{31} を有する第3収斂群 G_3 を経て、中央に開口を持ち光軸に対して45°で斜設された第2平面鏡 M_2 の開口内にそのパターンの第2中間像を結像し、この第2中間像からの光が第2凹面反射鏡 M_2 よりなる第4収斂群 G_4 に至り、第4収斂群 G_4 で反射された光が第2平面鏡 M_2 の周辺で反射される。このように反射された光が、第5収斂群 G_5 を経てウエハ11の表面にそのパターンの第3中間像を結像する。

【0047】また、図7は図6中の第1収斂群 G_1 の詳細な構成を示し、この図7に示すように、第1収斂群 G_1 はレチクル10側から順に、レチクル10に凸面を向けた正メニスカスレンズ L_{11} 、両凸レンズ(以下、単に「凸レンズ」という) L_{12} 、レチクル10に凹面を向けた正メニスカスレンズ L_{13} 及びレチクル10に凸面を向けた正メニスカスレンズ L_{14} より構成されている。また、図6に示すように、第3収斂群 G_3 は、レチクル10に凹面を向けた正メニスカスレンズ L_{31} 、凹面反射鏡 M_{31} 及びレチクル10に凹面を向けた正メニスカスレンズ L_{32} より構成され、第5収斂群 G_5 は、第1収斂群 G_1 と対称に構成されている。

【0048】即ち、本例は、光軸近傍に開口を有する2枚の平面鏡、3枚の凹面反射鏡及び10枚の屈折レンズよりなる対称型の光学系となっており、開口数は0、45、像高は10mm、最大ミラー半径は486mmである。但し、ほとんど無収差に近い光学性能となっているので、光学系の比例拡大により、像高を2倍~3倍に拡大することが出来ることは明らかである。

【0049】屈折レンズは全て溶融石英よりなる一種類の光学ガラスを使っているが、紫外線エキシマレーザー光の193nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また球面収差、コマ収差、非点収差、歪曲収差も良好に補正されている。図6の第1実施例における曲率半径 r_i 、面間隔 d_i 及び硝材を次の表1に示す。以下の表において、第10面、第14面及び第18面はそれぞれ凹面反射鏡を展開光路図で表すための仮想面である。

【0050】

【表1】

i	r_i	d_i	硝材	i	r_i	d_i	硝材
0		15.5		15	137.56	53.0	
1	125.97	18.5	SiO ₂	16	206.41	1148.7	
2	138.88	1.0		17	-1189.91	0.0	
3	425.68	19.0	SiO ₂	18	∞	1188.0	
4	-190.98	7.0		19	-327.82	31.0	SiO ₂
5	-69.10	7.0	SiO ₂	20	-310.82	0.1	
6	-55.19	0.1		21	55.19	7.0	SiO ₂
7	310.82	31.0	SiO ₂	22	69.10	7.0	
8	327.82	1188.0		23	190.98	19.0	SiO ₂
9	-1189.91	0.0		24	-425.68	1.0	
10	∞	1148.7		25	-138.88	18.5	SiO ₂
11	-206.41	53.0	SiO ₂	26	-125.97	15.4	
12	-137.56	1191.0					
13	-277.08	0.0					
14	∞	1191.0					

【0051】また、図8 (a) ~ (c) は第1実施例の縦収差図、図8 (c) は第1実施例の倍率色収差図、図8 (e) は第1実施例の横収差図を示す。これらの収差図において、符号J、P及びQは使用波長がそれぞれ248.4 nm、247.9 nm及び248.9 nmであることを示す。これら収差図より、本例においては開口数が0.45と大きいにも拘らず、広いイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も良好に補正されている。

【0052】なお、図6において、開口を有する平面鏡M₁ M₃の代わりにそれぞれ図5に示すような小型平面鏡M₁' M₃'を使用しても、等価な光学系が実現できることは既に説明した通りである。更に、平面鏡M₁ M₃の代わりに、開口を有する凹面鏡又は凸面鏡を使用しても良く、更に小型凹面鏡や小型凸面鏡を使用しても良い。

【0053】【第2実施例】この第2実施例も等倍の投影光学系の例である。図9は第2実施例の投影光学系の展開光路図であり、この図9に示すように、レチクル10上のパターンからの光が、第1収斂群G₁を経て、中央に開口を持ち光軸に対して45°で斜設された第1平

面鏡M₁の周辺部で反射された後、第1凹面反射鏡M₂を含む第2収斂群G₂に至り、第2収斂群G₂で反射された光が第1平面鏡M₁の開口内にそのパターンの第1中間像を結像する。そして、この第1中間像からの光が、第3収斂群G₃を経て、中央に開口を持ち光軸に対して45°で斜設された第2平面鏡M₂の開口内にそのパターンの第2中間像を結像し、この第2中間像からの光が第2凹面反射鏡M₄を含む第4収斂群G₄に至り、第4収斂群G₄で反射された光が第2平面鏡M₃の周辺で反射される。このように反射された光が、第5収斂群G₅を経てウエハ11の表面にそのパターンの第3中間像を結像する。

【0054】また、図9に示すように、第1収斂群G₁はレチクル10側から順に、凸レンズL₁₁、両凹レンズ(以下、単に「四レンズ」という)L₁₂、レチクル10に凹面を向けた正メニスカスレンズL₁₃及びレチクル10に凸面を向けた負メニスカスレンズL₁₄より構成され、第2収斂群G₂は、レチクル10に凹面を向けた負メニスカスレンズL₂₁及び凹面反射鏡M₂よりなるマンジンミラーである。また、第3収斂群G₃は、凹レンズL₂₂、凸レンズL₂₃、凹レンズL₂₄、レチクル10に凹

面を向けた正メニスカスレンズ L_{34} 、レチクル10に凸面を向けた負メニスカスレンズ L_{35} 、レチクル10に凹面を向けた正メニスカスレンズ L_{36} 、凸レンズ L_{37} 、レチクル10に凸面を向けた負メニスカスレンズ L_{38} 、凸レンズ L_{39} 及びこれらのレンズ $L_{31} \sim L_{39}$ と対称なレンズ $L_{34} \sim L_{39}$ より構成されている。

【0055】そして、第4収斂群 G_4 は、レチクル10に凹面を向けた負メニスカスレンズ L_{41} 及び第2凹面反射鏡 M_4 よりなるマンジンミラーであり、第5収斂群 G_5 は、第1収斂群 G_1 と対称に構成されている。即ち、本例は、中央に開口を持つ2枚の平面鏡、2枚の凹面反射鏡及び2枚の屈折レンズよりなる対称型の光学系となっており、開口数は0.45、像高は5mm、最大ミラー半径は7.5mmである。但し、本例もほとんど無収差に近い光学性能が得られているので、光学系の比例拡大により、像高を2倍～3倍と更に大きくすることが出来ることは明らかである。

【0056】また、第2収斂群 G_2 及び第4収斂群 G_4 は、それぞれ一枚の負メニスカスレンズを含み、屈折レンズと凹面反射鏡とが分離されたタイプのマンジンミラーの構成をとっている。このように、第2凹面反射鏡 M_2 を含む第2収斂群 G_2 が、負メニスカスレンズ L_{21} を含むマンジンミラーであると、少ない種類の光学ガラス

でも軸上の色収差を容易に除去することが出来る。同様に、第2凹面反射鏡 M_4 を含む第4収斂群 G_4 が、負メニスカスレンズ L_{41} を含むマンジンミラーである場合も、少ない種類の光学ガラスで軸上の色収差を容易に除去することが出来る。

【0057】従って、この第2実施例のように、第2収斂群 G_2 が、負メニスカスレンズを含むマンジンミラーであり、且つ第4収斂群 G_4 も、負メニスカスレンズを含むマンジンミラーである場合には、全体として少ない種類の光学ガラスで軸上の色収差を容易に除去することが出来る。本例の光学系も、屈折レンズは全て溶融石英よりなる一種類の光学ガラスを使っているが、紫外線エキシマレーザー光の248nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また球面収差、コマ収差、非点収差及び歪曲収差も良好に補正された結像性能の優れた光学系となっている。

【0058】第2実施例における曲率半径 r_1 、面間隔 d_1 及び硝材を次の表2に示す。以下の表において、第12面及び第53面はそれぞれ凹面反射鏡を展開光路図で表すための仮想面である。

【0059】

【表2】

i	r_i	d_i	硝材	i	r_i	d_i	硝材
0	—	12.0		33	129.52	15.0	SiO ₂
1	259.01	10.0	SiO ₂	34	-169.96	2.5	
2	-55.98	1.0		35	-213.06	7.5	SiO ₂
3	-77.91	7.0	SiO ₂	36	-437.70	0.1	
4	265.03	2.0		37	104.95	11.1	SiO ₂
5	-235.04	10.0	SiO ₂	38	-523.65	0.5	
6	-32.95	0.1		39	108.51	11.2	SiO ₂
7	383.80	10.0	SiO ₂	40	159.04	5.0	
8	190.09	161.5		41	-144.67	9.3	SiO ₂
9	-129.13	10.0	SiO ₂	42	-1584.18	0.3	
10	-222.54	12.0		43	56.77	11.2	SiO ₂
11	-158.01	0.0		44	182.94	2.1	
12	∞	12.0		45	-3429.20	7.5	SiO ₂
13	222.54	10.0	SiO ₂	46	35.03	0.3	
14	129.13	154.4		47	33.24	11.2	SiO ₂
15	-42.66	7.5	SiO ₂	48	-146.57	0.3	
16	862.47	0.3		49	-862.47	7.5	SiO ₂
17	146.57	11.2	SiO ₂	50	42.66	154.4	
18	-33.24	0.3		51	-129.13	10.0	SiO ₂
19	-35.03	7.5	SiO ₂	52	-222.54	12.0	
20	3429.20	2.1		53	∞	0.0	
21	-182.94	11.2	SiO ₂	54	158.01	12.0	
22	-56.77	0.3		55	222.54	10.0	SiO ₂
23	1584.18	9.3	SiO ₂	56	129.13	161.5	
24	144.67	5.0		57	-190.09	10.0	SiO ₂
25	-159.04	11.2	SiO ₂	58	-383.80	0.1	
26	-108.51	0.5		59	32.95	10.0	SiO ₂
27	523.65	11.1	SiO ₂	60	235.04	2.0	
28	-104.95	0.1		61	-265.03	7.0	SiO ₂
29	437.70	7.5	SiO ₂	62	77.91	1.0	
30	213.06	2.5		63	55.98	10.0	SiO ₂
31	169.96	15.0	SiO ₂	64	-259.01	11.9	
32	-129.52	135.0					

【0060】また、図10 (a) ~ (c) は第2実施例の縦収差図、図10 (c) は第2実施例の倍率色収差図、図10 (e) は第2実施例の横収差図を示す。これら収差図より、本例においても開口数が0.45と大きいにも拘らず、広いイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も

良好に補正されている。

【0061】【第3実施例】この第3実施例は縮小投影を行う投影光学系の例である。図11は第3実施例の投影光学系の展開光路図であり、この図11に示すように、レチクル10上のパターンからの光が、第1収斂群G₁を経て、中央に開口を持ち光軸に対して45°で斜

設された第1平面鏡M₁の周辺部で反射された後、第1凹面反射鏡M₂を含む第2収斂群G₂に至り、第2収斂群G₂で反射された光が第1平面鏡M₁の開口内にそのパターンの第1中間像を結像する。そして、この第1中間像からの光が、第3収斂群G₃を経て、中央に開口を持ち光軸に対して45°で斜設された第2平面鏡M₃の開口内にそのパターンの第2中間像を結像し、この第2中間像からの光が第2凹面反射鏡M₄を含む第4収斂群G₄に至り、第4収斂群G₄で反射された光が第2平面鏡M₃の周辺で反射される。このように反射された光が、第5収斂群G₅を経てウエハ11の表面にそのパターンの第3中間像を結像する。

【0062】また、図11に示すように、第1収斂群G₁はレチクル10側から順に、レチクル10に凹面を向けた正メニスカスレンズL₁₁、レチクル10に凸面を向けた負メニスカスレンズL₁₂、凸レンズL₁₃及びレチクル10に凸面を向けた負メニスカスレンズL₁₄より構成され、第2収斂群G₂は、レチクル10に凹面を向けた負メニスカスレンズL₂₁及び凹面反射鏡M₂よりなるマンジンミラーである。また、第3収斂群G₃は、レチクル10に凹面を向けた負メニスカスレンズL₃₁、レチクル10に凹面を向けた正メニスカスレンズL₃₂、レチクル10に凹面を向けた負メニスカスレンズL₃₃、レチクル10に凹面を向けた正メニスカスレンズL₃₄、レチクル10に凹面を向けた正メニスカスレンズL₃₅、レチクル10に凹面を向けた正メニスカスレンズL₃₆、凸レンズL₃₇、凸レンズL₃₈、凸レンズL₃₉、凸レンズL₃₁₀、レチクル10に凹面を向けた正メニスカスレンズL₃₁₁、レチクル10に凹面を向けた負メニスカスレンズL₃₁₂、レチクル10に凹面を向けた正メニスカスレンズL₃₁₃、凹レンズL₃₁₄、凸レンズL₃₁₅及びレチクル10に凸面を向けた正メニスカスレンズL₃₁₆より構成されている。

【0063】そして、第4収斂群G₄は、レチクル10に凹面を向けた負メニスカスレンズL₄₁及び第2凹面反射鏡M₄よりなるマンジンミラーであり、第5収斂群G₅は、レチクル10に凸面を向けた正メニスカスレンズL₅₁、レチクル10に凸面を向けた負メニスカスレンズL₅₂、レチクル10に凸面を向けた正メニスカスレンズL₅₃、レチクル10に凹面を向けた負メニスカスレンズL₅₄及びレチクル10に凸面を向けた正メニスカスレンズL₅₅より構成されている。

【0064】即ち、本例は、中央に開口を持つ2枚の平面鏡、2枚の凹面反射鏡及び27枚の屈折レンズより構成されており、結像倍率は0.25倍、開口数は0.45、物体高は20mm、最大ミラー半径は75mmである。本例も、ほとんど無収差に近い光学性能となっているので、光学系の比例拡大により、像高を2倍～3倍と更に大きくすることが出来ることは明らかである。また、第2収斂群G₂及び第4収斂群G₄は、それぞれ1枚の負メニスカスレンズを含み、屈折レンズと反射鏡とが分離されたタイプのマンジンミラーの構成をとっている。

【0065】本例の光学系も、屈折レンズは全て溶融石英よりなる一種類の光学ガラスを使っているが、紫外線エキシマレーザー光の193nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また、球面収差、コマ収差、非点収差及び歪曲収差も良好に補正された結像性能の優れた光学系となっている。

【0066】第3実施例における曲率半径r_i、面間隔d_i及び硝材を次の表3に示す。以下の表において、第12面及び第49面はそれぞれ凹面反射鏡を展開光路図で表すための仮想面である。

【0067】

【表3】

i	r_i	d_i	硝材	i	r_i	d_i	硝材
0	—	10.0		33	172.29	11.0	SiO ₂
1	-71.38	8.0	SiO ₂	34	-944.95	0.5	
2	-61.85	35.0		35	99.77	11.2	SiO ₂
3	231.03	6.0	SiO ₂	36	319.67	4.0	
4	71.51	35.0		37	-143.57	9.0	SiO ₂
5	4288.57	12.0	SiO ₂	38	-2409.53	0.3	
6	-77.96	33.1		39	54.72	10.0	SiO ₂
7	552.21	6.0	SiO ₂	40	56.03	5.0	
8	78.03	170.0		41	-61.33	4.0	SiO ₂
9	-140.25	10.0	SiO ₂	42	45.57	1.5	
10	-215.61	39.9		43	50.21	12.0	SiO ₂
11	-186.04	0.0	SiO ₂	44	-46.06	0.3	
12	∞	39.9		45	26.02	7.5	SiO ₂
13	215.61	10.0	SiO ₂	46	113.79	127.3	
14	140.25	125.0		47	-130.37	10.0	SiO ₂
15	-16.54	5.0	SiO ₂	48	-279.95	35.9	
16	-72.83	0.3		49	∞	0.0	
17	-638.23	10.0	SiO ₂	50	167.11	35.9	
18	-33.20	5.0		51	279.95	10.0	SiO ₂
19	-23.16	5.0	SiO ₂	52	130.37	184.6	
20	-36.09	0.3		53	102.70	8.0	SiO ₂
21	-592.11	11.0	SiO ₂	54	298.78	0.5	
22	-56.28	0.3		55	31.06	8.0	SiO ₂
23	2342.59	7.0	SiO ₂	56	30.01	7.0	
24	97.46	7.0		57	56.85	7.5	SiO ₂
25	-363.12	11.0	SiO ₂	58	140.95	5.0	
26	-104.21	0.5		59	-92.02	7.0	SiO ₂
27	-1285.64	11.0	SiO ₂	60	-103.29	0.5	
28	-166.22	0.3		61	24.55	8.0	SiO ₂
29	116.73	15.0	SiO ₂	62	51.79	12.0	
30	-222.57	50.0					
31	945.64	14.0	SiO ₂				
32	-133.90	8.0					

【0068】また、図12 (a) ~ (c) は第3実施例の縦収差図、図12 (c) は第3実施例の倍率色収差図、図12 (e) は第3実施例の横収差図を示す。これら収差図より、本例においても開口数が0.45と大きいにも拘らず、広いイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も

良好に補正されている。

【0069】【第4実施例】この第4実施例は、縮小投影を行うと共に第3収斂群G₃を省略したタイプの投影光学系である。即ち、本例は図3の光学系に対応する実施例である。図13は第4実施例の投影光学系の展開光路図であり、この図13に示すように、レチクル10上

のパターンからの光が、第1収斂群G₁を経て、中央に開口を持ち光軸に対して45°で斜設された平面鏡M₁の表面の周辺部で反射された後、第1凹面反射鏡M₁を含む第2収斂群G₂に至り、第2収斂群G₂で反射された光が平面鏡M₁の開口内にそのパターンの中間像を結像する。そして、この中間像からの光が第2凹面反射鏡M₄を含む第4収斂群G₄に至り、第4収斂群G₄で反射された光が平面鏡M₁の裏面の周辺で反射される。このように反射された光が、第5収斂群G₅を経てウエハ11の表面にそのパターンの像を結像する。本例の平面鏡M₁は、例えば図6の第1平面鏡M₁と第2平面鏡M₂とを貼り合わせたものと等価である。

【0070】また、図13に示すように、第1収斂群G₁はレチクル10側から順に、レチクル10に凸面を向けた負メニスカスレンズL₁₁、凸レンズL₁₂、レチクル10に凸面を向けた負メニスカスレンズL₁₃、レチクル10に凸面を向けた正メニスカスレンズL₁₄、レチクル10に凸面を向けた負メニスカスレンズL₁₅、レチクル10に凸面を向けた正メニスカスレンズL₁₆、凸レンズL₁₇、レチクル10に凹面を向けた負メニスカスレンズL₁₈及びレチクル10に凸面を向けた正メニスカスレンズL₁₉より構成され、第2収斂群G₂は、レチクル10に凹面を向けた負メニスカスレンズL₂₁及び凹面反射鏡M₂よりなるマンジンミラーである。

【0071】また、第4収斂群G₄は、レチクル10に凹面を向けた負メニスカスレンズL₄₁及び第2凹面反射鏡M₄よりなるマンジンミラーであり、第5収斂群G₅は、凸レンズL₅₁、レチクル10に凹面を向けた負メニスカスレンズL₅₂、レチクル10に凸面を向けた正メニ

スカスレンズL₅₃、レチクル10に凸面を向けた正メニスカスレンズL₅₄、レチクル10に凸面を向けた負メニスカスレンズL₅₅、凸レンズL₅₆、レチクル10に凹面を向けた負メニスカスレンズL₅₇、凸レンズL₅₈及び凹レンズL₅₉より構成されている。

【0072】即ち、本例は、中央に開口を持つ1枚の平面鏡（正確には2枚の平面鏡を貼り合わせた平面鏡）、2枚の凹面反射鏡及び2枚の屈折レンズより構成され、結像倍率は0.2倍、開口数は0.5、物体高は25mm、最大ミラー半径は115mmである。但し、本例もほとんど無収差に近い光学性能となっているので、光学系の比例拡大により、像高を2倍～3倍と更に大きくすることが出来ることは明らかである。また、第2収斂群G₂及び第4収斂群G₄はそれぞれ、1枚の負メニスカスレンズを含み、屈折レンズと反射鏡とが分離されたタイプのマンジンミラーの構成をとっている。

【0073】本例の光学系において、屈折レンズは溶融石英及び萤石の2種類の光学ガラスを使っているが、紫外線エキシマレーザー光の248nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また球面収差、コマ収差、非点収差及び歪曲収差も良好に補正された結像性能の優れた光学系となっている。

【0074】第4実施例における曲率半径r₁、面間隔d₁及び硝材を次の表4に示す。以下の表において、第21面及び第27面はそれぞれ凹面反射鏡を展開光路図で表すための仮想面である。

【0075】

【表4】

i	r_i	d_i	硝材	i	r_i	d_i	硝材
0	—	121.4		25	-440.69	17.0	SiO ₂
1	767.44	15.0	SiO ₂	26	-2852.06	12.0	
2	163.77	4.0		27	∞	0.0	
3	166.54	25.0	SiO ₂	28	416.58	12.0	
4	-505.97	0.5		29	2852.06	17.0	SiO ₂
5	233.77	18.0	SiO ₂	30	440.69	432.6	
6	149.40	6.5		31	289.73	30.0	CaF ₂
7	166.94	23.5	SiO ₂	32	-246.70	3.5	
8	469.37	298.5		33	-193.54	10.0	SiO ₂
9	606.70	15.0	SiO ₂	34	-599.60	0.5	
10	238.92	20.0		35	144.65	20.0	CaF ₂
11	-359.02	30.0	SiO ₂	36	1180.27	0.5	
12	-210.62	100.0		37	94.98	32.0	CaF ₂
13	3003.74	30.0	SiO ₂	38	342.58	2.9	
14	-689.22	9.5		39	1588.35	12.0	SiO ₂
15	-329.44	20.0	SiO ₂	40	61.18	3.0	
16	-896.85	1.5		41	60.40	27.0	CaF ₂
17	306.66	30.0	SiO ₂	42	-523.49	2.5	
18	1333.63	447.0		43	-217.42	12.0	SiO ₂
19	-414.75	17.0	SiO ₂	44	-620.70	2.0	
20	-1772.13	12.0		45	62.05	18.0	CaF ₂
21	∞	0.0		46	-518.54	2.0	
22	427.51	12.0		47	-653.52	10.0	SiO ₂
23	1772.13	17.0	SiO ₂	48	600.35	12.0	
24	414.75	652.6					

【0076】また、図14(a)～(c)は第4実施例の縦収差図、図14(c)は第4実施例の倍率色収差図、図14(e)は第4実施例の横収差図を示す。これら収差図より、本例においても開口数が0.45と大きいにも拘らず、広いイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も良好に補正されている。

【0077】【第5実施例】この第5実施例は、縮小投影を行うと共に第4収斂群G₁及び第5収斂群G₂を省略したタイプの投影光学系である。即ち、本例は図1の光学系に対応する実施例である。図15はこの第5実施例の投影光学系の展開光路図であり、この図15に示すように、レチクル10上のパターンからの光が、第1収斂群G₁を経て、中央に開口を持ち光軸に対して45°で斜設された平面鏡M₁の周辺部で反射された後、凹面反射鏡M₂を含む第2収斂群G₂に至り、第2収斂群G

で反射された光が平面鏡M₁の開口内にそのパターンの中間像を結像する。そして、この中間像からの光が、第3収斂群G₃を経て、ウエハ11の表面にそのパターンの像を結像する。

【0078】また、図15に示すように、第1収斂群G₁はレチクル10側から順に、レチクル10に凸面を向けた正メニスカスレンズL₁₁、レチクル10に凸面を向けた負メニスカスレンズL₁₂、凸レンズL₁₃及び凹レンズL₁₄より構成され、第2収斂群G₂は、レチクル10に凹面を向けた負メニスカスレンズL₂₁及び凹面反射鏡M₂よりなるマンジンミラーである。また、第3収斂群G₃は、レチクル10に凹面を向けた正メニスカスレンズL₃₁、レチクル10に凹面を向けた正メニスカスレンズL₃₂、凸レンズL₃₃、レチクル10に凸面を向けた負メニスカスレンズL₃₄、凸レンズL₃₅、凸レンズL₃₆、レチクル10に凹面を向けた負メニスカスレンズL₃₇、

凸レンズ L_{18} 、レチクル10に凸面を向けた正メニスカスレンズ L_{19} 、レチクル10に凹面を向けた負メニスカスレンズ L_{20} 、凸レンズ L_{21} 、レチクル10に凸面を向けた負メニスカスレンズ L_{22} 、レチクル10に凸面を向けた正メニスカスレンズ L_{23} 及びレチクル10に凸面を向けた負メニスカスレンズ L_{24} より構成されている。

【0079】即ち、本例は、中央に開口を持つ1枚の平面鏡、1枚の凹面反射鏡及び19枚の屈折レンズより構成され、結像倍率は0.25倍、開口数は0.45、像高は5mm、最大ミラー直径は75mmである。但し、本例もほとんど無収差に近い光学性能となっているので、光学系の比例拡大により、像高を2倍～3倍と更に大きくすることが出来ることは明らかである。また、第2収斂群 G_2 は、1枚の負メニスカスレンズを含み、屈折レンズと反射鏡とが分離されたタイプのマンジンミラ

ーの構成をとっている。

【0080】本例の光学系も、屈折レンズは全て溶融石英よりなる一種類の光学ガラスを使っているが、紫外線エキシマレーザー光の193nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また、球面収差、コマ収差、非点収差及び歪曲収差も良好に補正された結像性能の優れた光学系となっている。

【0081】第5実施例における曲率半径 r_1 、面間隔 d_1 及び硝材を次の表5に示す。以下の表において、第12面は凹面反射鏡を展開光路図で表すための仮想面である。

【0082】

【表5】

i	r _i	d _i	硝材	i	r _i	d _i	硝材
0	-	2.2		25	148.11	8.0	SiO ₂
1	35.81	8.0	SiO ₂	26	-277.55	2.6	
2	59.46	12.6		27	-68.13	7.5	SiO ₂
3	356.73	6.0	SiO ₂	28	-144.78	0.3	
4	30.20	11.7		29	111.88	11.0	SiO ₂
5	41.51	8.0	SiO ₂	30	-244.49	0.5	
6	-300.87	7.3		31	78.03	11.0	SiO ₂
7	-79.79	6.0	SiO ₂	32	335.30	5.0	
8	-50.60	221.9		33	-89.48	9.0	SiO ₂
9	-110.93	10.0	SiO ₂	34	-178.22	3.0	
10	-226.62	6.0		35	61.88	8.0	SiO ₂
11	-126.76	0.0		36	-734.75	5.0	
12	∞	6.0		37	47.13	6.0	SiO ₂
13	226.62	10.0	SiO ₂	38	22.27	2.0	
14	110.93	119.9		39	26.01	8.5	SiO ₂
15	-31.41	8.0	SiO ₂	40	208.27	3.0	
16	-28.37	1.0		41	18.76	5.0	SiO ₂
17	-76.17	6.0	SiO ₂	42	15.39	11.9	
18	-38.10	1.0					
19	130.38	8.0	SiO ₂				
20	-122.63	1.0					
21	76.08	9.4	SiO ₂				
22	61.43	34.9					
23	172.92	8.0	SiO ₂				
24	-139.74	1.0					

【0083】また、図16 (a) ~ (c) は第5実施例の縦収差図、図16 (c) は第5実施例の倍率色収差図、図16 (e) は第5実施例の横収差図を示す。これら収差図より、本例においても開口数が0.45と大きいにも拘らず、広いイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も良好に補正されている。

【0084】[第6実施例] この第6実施例は縮小投影を行うと共に、第1収斂群G₁及び第2収斂群G₂を省略した投影光学系である。即ち、本例は図2の光学系に対応するものである。図17は第6実施例の投影光学系の展開光路図であり、この図17に示すように、レチクル10上のパターンからの光が、第3収斂群G₃を経

て、中央に開口を持ち光軸に対して45°で斜設された平面鏡M₃の開口内にそのパターンの中間像を結像し、この第2中間像からの光が凹面反射鏡M₄を含む第4収斂群G₄に至り、第4収斂群G₄で反射された光が平面鏡M₅の周辺で反射される。このように反射された光が、第5収斂群G₅を経てウエハ11の表面にそのパターンの像を結像する。

【0085】また、図17に示すように、第3収斂群G₃はレチクル10から順に、レチクル10に凸面を向けた負メニスカスレンズL₃₁、レチクル10に凸面を向けた負メニスカスレンズL₃₂、レチクル10に凹面を向けた負メニスカスレンズL₃₃、レチクル10に凸面を向けた負メニスカスレンズL₃₄、レチクル10に凹面を向け

た正メニスカスレンズL₃₅、凸レンズL₃₆、レチクル10に凹面を向けた正メニスカスレンズL₃₇、凸レンズL₃₈、レチクル10に凹面を向けた正メニスカスレンズL₃₉、凸レンズL₄₀、凸レンズL₄₁、レチクル10に凹面を向けた負メニスカスレンズL₄₂、レチクル10に凹面を向けた負メニスカスレンズL₄₃、凹レンズL₄₄、凸レンズL₄₅及び凸レンズL₄₆より構成されている。

【0086】そして、第4収斂群G₄は、レチクル10に凹面を向けた負メニスカスレンズL₄₄及び凹面反射鏡M₄よりなるマンジンミラーであり、第5収斂群G₅は、レチクル10に凸面を向けた正メニスカスレンズL₅₁、レチクル10に凸面を向けた負メニスカスレンズL₅₂、レチクル10に凸面を向けた正メニスカスレンズL₅₃、レチクル10に凹面を向けた正メニスカスレンズL₅₄及びレチクル10に凸面を向けた負メニスカスレンズL₅₅より構成されている。

【0087】即ち、本例は、中央に開口を持つ1枚の平面鏡、1枚の凹面反射鏡及び2枚の屈折レンズより構成され、結像倍率は0.25倍、開口数は0.3、像高は3mm、最大ミラー直径は41mmである。但し、本

例もほとんど無収差に近い光学性能となっているので、光学系の比例拡大により、像高を2倍～3倍と更に大きくすることが出来ることは明らかである。また、第4収斂群G₄は、1枚の負メニスカスレンズを含み、屈折レンズと反射鏡とが分離されたタイプのマンジンミラーの構成をとっている。

【0088】本例の光学系も、屈折レンズは全て溶融石英よりなる一種類の光学ガラスを使っているが、紫外線エキシマレーザー光の193nmの波長における、1nmの波長幅に対して、軸上及び軸外の色消しがなされている。また、球面収差、コマ収差、非点収差及び歪曲収差も良好に補正された結像性能の優れた光学系となっている。

【0089】第6実施例における曲率半径r₁、面間隔d₁及び硝材を次の表6に示す。以下の表において、第35面は凹面反射鏡を展開光路図で表すための仮想面である。

【0090】

【表6】

i	r ₁	d ₁	硝材	i	r ₁	d ₁	硝材
0	-	4.0		25	48.77	10.0	SiO ₂
1	95.98	10.0	SiO ₂	26	43.54	5.0	
2	65.75	12.0		27	-112.55	4.0	SiO ₂
3	1434.55	7.0	SiO ₂	28	21.60	1.5	
4	60.07	11.0		29	204.26	12.0	SiO ₂
5	-23.22	10.0	SiO ₂	30	-34.05	0.3	
6	-27.51	0.3		31	24.14	7.5	SiO ₂
7	251.93	8.0	SiO ₂	32	-42.62	140.0	
8	51.85	8.0		33	-131.63	10.5	SiO ₂
9	-68.40	7.0	SiO ₂	34	-280.63	5.2	
10	-66.60	51.0		35	∞	0.0	
11	763.14	15.0	SiO ₂	36	143.16	5.2	
12	-105.25	2.0		37	280.63	10.5	SiO ₂
13	-2171.46	11.0	SiO ₂	38	131.63	175.6	
14	-398.28	0.6		39	99.65	8.0	SiO ₂
15	657.88	15.0	SiO ₂	40	856.91	0.5	
16	-195.65	65.0		41	34.40	8.0	SiO ₂
17	-1397.29	14.0	SiO ₂	42	28.44	7.0	
18	-159.18	8.0		43	44.86	7.5	SiO ₂
19	238.03	11.0	SiO ₂	44	115.52	5.0	
20	-292.91	0.5		45	-79.28	7.0	SiO ₂
21	90.28	11.2	SiO ₂	46	-66.11	0.5	
22	-713.33	4.0		47	22.09	8.0	SiO ₂
23	-101.29	9.0	SiO ₂	48	18.08	11.9	
24	-216.96	0.3					

【0091】また、図18(a)～(c)は第6実施例の縦収差図、図18(c)は第6実施例の倍率色収差図、図18(e)は第6実施例の横収差図を示す。これら収差図より、本例においても開口数が0.3でありイメージサークルの領域内で諸収差が良好に補正されていることが分かる。また、色収差も良好に補正されている。

【0092】次に、本発明では(1)式～(4)式の条件を満足することが望ましいとされているが、以下に、上述の各実施例とそれらの条件との対応について説明する。先ず、上述の各実施例における第1収斂群G₁～第5収斂群G₅のそれぞれの焦点距離をf_i(i=1～5)、それぞれのペツツバール和をp_i(i=1～5)、

それぞれの見かけの屈折率をn_i(i=1～5)、それぞれの結像倍率をβ_i(i=1～5)とする。また、第2収斂群G₂中の第1凹面反射鏡M₂及び第4収斂群G₄中の第2凹面反射鏡M₄の曲率半径をそれぞれR_i(i=2, 4)として、第1収斂群G₁及び第2収斂群G₂の合成の結像倍率をβ₁₂、第4収斂群G₄及び第5収斂群G₅の合成の結像倍率をβ₄₅として、これらの結像倍率β₁₂及びβ₄₅をβ₁₂₄₅で表す。上述の第1実施例～第6実施例の諸元をそれぞれ以下の表7～表12にまとめる。但し、全系をG₁で表し、全系G₁に対応するペツツバール和p₁及び結像倍率をβ₁の欄にはそれぞれ全系のペツツバール和及び結像倍率を示す。

【0093】

【表7】

第1実施例の諸元

＼	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	145.01	0.00436	1.581705	1.33	-1.17
G ₂	-1190	594.96	-0.00168	-1.000000	-0.876	
G ₃	—	146.71	-0.00548	-1.243795	-1.00	-1.00
G ₄	-1190	594.96	-0.00168	-1.000000	-1.14	-0.85
G ₅	—	145.01	0.00436	1.581705	0.75	
G _T	—	—	-0.0001	—	-1.00	-1.00

【0094】

【表8】

第2実施例の諸元

＼	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	70.19	0.00960	1.483971	1.70	-1.12
G ₂	-158	95.26	-0.01485	-0.70688	-0.66	
G ₃	—	114.70	0.01008	0.86487	-1.00	-1.00
G ₄	-158	95.26	-0.01485	-0.70688	-1.52	-0.90
G ₅	—	70.19	0.00960	1.483971	0.59	
G _T	—	—	-0.0004	—	-1.01	-1.01

【0095】

【表9】

第3実施例の諸元

＼	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	-793.98	-0.00196	0.642	0.826	-0.412
G ₂	-186	103.76	-0.01254	-0.768	-0.4988	
G ₃	—	104.63	0.01688	0.566	-0.7755	-0.7755
G ₄	-167	102.82	-0.01491	-0.653	-2.425	-0.7828
G ₅	—	52.26	0.01294	1.483	0.3228	
G _T	—	—	0.00040	—	-0.25	-0.25

【0096】

【表10】

第4実施例の諸元

＼	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	508.51	0.00216	0.91045	35.70	-0.645
G ₂	-428	333.45	-0.00592	-0.50658	-0.0181	
G ₃	—	—	—	—	—	—
G ₄	-417	328.19	-0.00609	-0.5003	-10.836	-0.313
G ₅	—	100.04	0.00983	1.01689	0.029	
G _T	—	—	-0.00003	—	0.20	-0.20

【0097】

【表11】

第5実施例の諸元

	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	-132.32	-0.00865	0.8737	0.5585	-0.254
G ₂	-127	82.86	-0.01909	-0.6322	-0.455	
G ₃	—	144.58	0.02795	0.2475	-0.9837	-0.9837
G ₄	—	—	—	—	—	—
G ₅	—	—	—	—	—	
G _T	—	—	0.00058	—	0.25	0.25

【0098】

【表12】

第6実施例の諸元

	R _i	f _i	p _i	n _i	β _i	β _{ij}
G ₁	—	—	—	—	—	—
G ₂	—	—	—	—	—	
G ₃	—	25.004	0.01409	2.8384	-0.2847	-0.2847
G ₄	-143	94.979	-0.01687	-0.6241	-2.2162	-0.8783
G ₅	—	84.227	0.00306	3.87995	0.3963	
G _T	—	—	0.00028	—	0.25	0.25

【0099】次に、上記の表7～表12に基づいて、条件式(1)～(4)のパラメータの値が各実施例でどのような値になっているのかを、次の表にまとめて示す。

【0100】

【表13】

条件式(1), (2), (3), (4)の対応表

条件式	実施例	1	2	3	4	5	6
(1) p ₁ +p ₃ +p ₅ >0	0.00324	0.02928	0.02786	0.01199	0.0193	0.017	
(1) p ₂ +p ₄ <0	-0.00336	-0.02970	-0.02745	-0.01201	-0.0191	-0.017	
(2) 0.1≤ β ₁₂ ≤2	1.17	1.12	0.4	0.65	0.25	—	
(3) 0.1≤ β ₃ ≤2	1.0	1.0	0.77	—	0.98	0.28	
(4) 0.1≤ β ₄₅ ≤2	0.85	0.9	0.78	0.31	—	0.88	

【0101】また、本発明では、条件式(9)及び(10)を満足することも望ましいとされているが、それら条件式(9)及び(10)に現れる第2収斂群G₂及び第4収斂群G₄の各パラメータR₂, p₂, n₂, R₄, p₄, n

の値が各実施例でどのような値となっているかを、次の表に示す。

【0102】

【表14】

条件式(9), (10)内の諸量の対応表(A)

諸量 実施例	R ₂	p ₂	n ₂	R ₄	p ₄	n ₄
1	1190.	-0.00168	-1.0	1190.	-0.00168	-1.0
2	158.	-0.01485	-0.70688	158.	-0.01485	-0.70688
3	186.	-0.01254	-0.768	167.	-0.01491	-0.653
4	428.	-0.00592	-0.50658	417.	-0.00609	-0.5003
5	127.	-0.01909	-0.6322	—	—	—
6	—	—	—	143.	-0.01687	-0.6241

【0103】また、表14より、各実施例において、条件式(9)及び(10)の諸量n₂p₂/|R₂|, n₄p₄/|R₄|はそれぞれ次のようになっている

る。

【0104】

【表15】

条件式(9), (10)内の諸量の対応表(B)

諸量 実施例	n ₂ p ₂	2/ R ₂	n ₄ p ₄	2/ R ₄
1	0.00168	0.00168	0.00168	0.00168
2	0.0104971	0.0126574	0.0104971	0.0126574
3	0.0096307	0.0107503	0.0097362	0.0107503
4	0.0029989	0.0046782	0.0030468	0.0048009
5	0.0120686	0.0157778	—	—
6	—	—	0.0105285	0.0139703

【0105】これらの各表より、上述の各実施例では何れも(1)式～(4)式の条件と、(9)式及び(10)式の条件とが満足されていることが分かる。なお、上述の各実施例においては、屈折光学系を構成する硝材として石英、萤石等の光学ガラスが使用されているが、石英、萤石等の光学ガラスは紫外線を通すことができるるので、好都合である。

【0106】但し、使用する照明光が赤外線である場合には、屈折光学系を構成する硝材として、シリコン(Si)、ゲルマニウム(Ge)、硫化亜鉛(ZnS)又はセレン化亜鉛(ZnSe)等の光学ガラスを使用することもできる。これらの硝材は赤外線に対する透過率が大きいからである。また、屈折光学系を構成する材料として、アクリル、ポリスチレン、ポリカーボネートなどのプラスチック光学材を使用するようにしてもよい。これにより、量産性のある、低成本の光学系を実現できる。

【0107】更に、有限の距離にあるレチクル10の代わりに、無限遠距離の物体の像を所定の観察面上に結像する所謂一般の撮像レンズに本発明を適用することもできる。また、上述の各実施例の光学系を、軸外光束のみを用いて、軸外輪帶状物体を投影し、レチクル10とウエハ11とを投影光学系の倍率に対応して異なる速度で移動しながら露光する、所謂スキャン露光用の露光装置

に適用することも可能である。これにより、投影光学系を小型化できる。

【0108】また、上述実施例は、等倍又は縮小投影光学系の例であるが、レチクル10とウエハ11との関係を逆にすることにより拡大投影光学系としても使えることは明らかである。このような拡大光学系の用途としては、紫外線顕微鏡等が有力である。このように、本発明は上述実施例に限定されず、本発明の要旨を逸脱しない範囲で種々の構成を取り得る。

【0109】

【発明の効果】本発明の第1の反射屈折投影光学系によれば、選択光学系により光束の光路を折り曲げると共に、凹面反射鏡からの光束でその選択光学系の光軸近傍に中間像を結像するか、又はその選択光学系の光軸近傍の中間像からの光を凹面反射鏡に導いている。従って、ペツツバール和及び軸上色収差を良好に補正できる。また、非対称光学系にありがちな歪曲収差及び倍率色収差も、一部の屈折光学系との組み合わせにより良好に補正することができ、球面収差及びコマ収差をも良好に補正することができる。従って、ビームスプリッターを用いること無く、且つ一括露光方式を取ることが出来る結像性能の優れた反射屈折投影光学系が提供できる利点がある。

【0110】また、本発明の第2の反射屈折投影光学系

によれば、ビームスプリッターを用いる必要が無く結像性能が優れていますと共に、一括露光方式を取ることが出来る。更に、2枚の凹面反射鏡を用いることにより、各凹面反射鏡の曲率半径を大きくでき収差を小さくできる利点がある。また、本発明の第3の反射屈折投影光学系によれば、ビームスプリッターを用いることが無く結像性能が優れていますと共に、一括露光方式を取ることが出来る。更に、2枚の凹面反射鏡を用いることにより、各凹面反射鏡の曲率半径を大きくでき収差を小さくできる利点がある。更に、第1選択光学系と第2選択光学系との間に第3収斂群が設けられているため、結像倍率や諸収差を広い範囲で制御できる利点がある。

【図面の簡単な説明】

【図1】本発明による反射屈折投影光学系の第1の基本構成を示す構成図である。

【図2】図1の基本構成の変形例を示す構成図である。

【図3】本発明による反射屈折投影光学系の第2の基本構成を示す構成図である。

【図4】本発明による反射屈折投影光学系の第3の基本構成を示す構成図である。

【図5】図4の基本構成の変形例を示す構成図である。

【図6】本発明の第1実施例の投影光学系を示す展開光路図である。

【図7】第1実施例中の第1収斂群G₁の詳細な構成を示す光路図である。

【図8】第1実施例の収差図である。

【図9】本発明の第2実施例の投影光学系を示す展開光路図である。

【図10】第2実施例の収差図である。

【図11】本発明の第3実施例の投影光学系を示す展開光路図である。

【図12】第3実施例の収差図である。

【図13】本発明の第4実施例の投影光学系を示す展開光路図である。

【図14】第4実施例の収差図である。

【図15】本発明の第5実施例の投影光学系を示す展開光路図である。

【図16】第5実施例の収差図である。

【図17】本発明の第6実施例の投影光学系を示す展開光路図である。

【図18】第6実施例の収差図である。

【符号の説明】

1 物体面

2 像面

10 レチクル

11 ウエハ

G₁ 第1収斂群

G₂ 第2収斂群

G₃ 第3収斂群

G₄ 第4収斂群

G₅ 第5収斂群

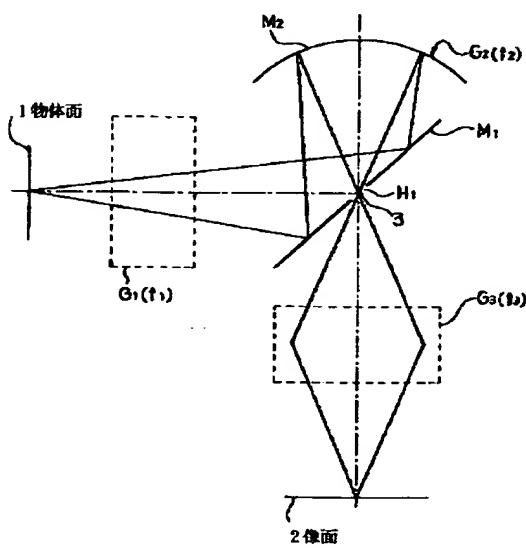
M₁, M₂ 開口を有する平面鏡

H₁, H₂ 開口

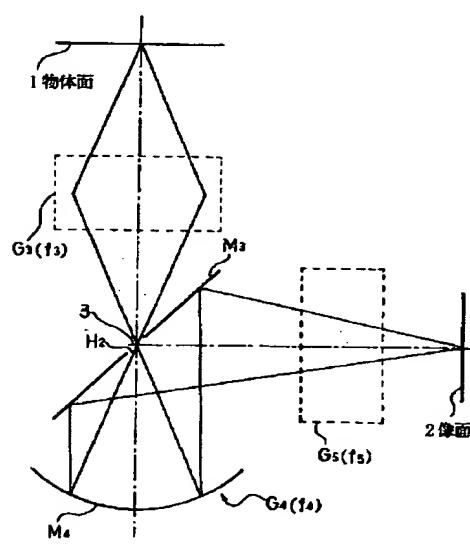
M₃, M₄ 凹面反射鏡

M₁', M₂' 微小平面鏡

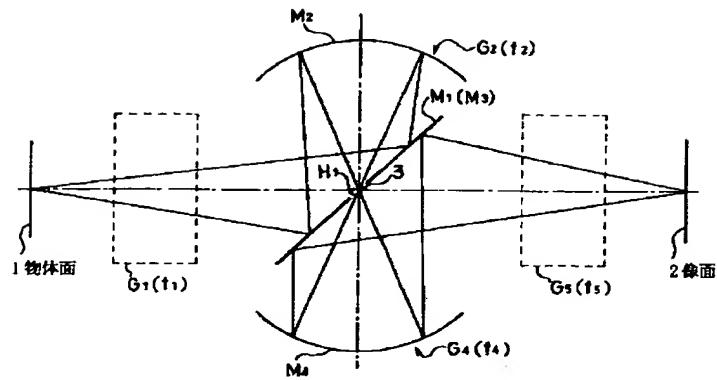
【図1】



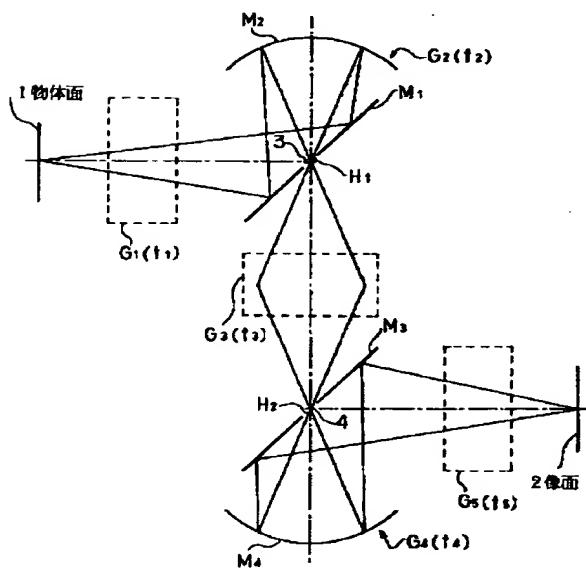
【図2】



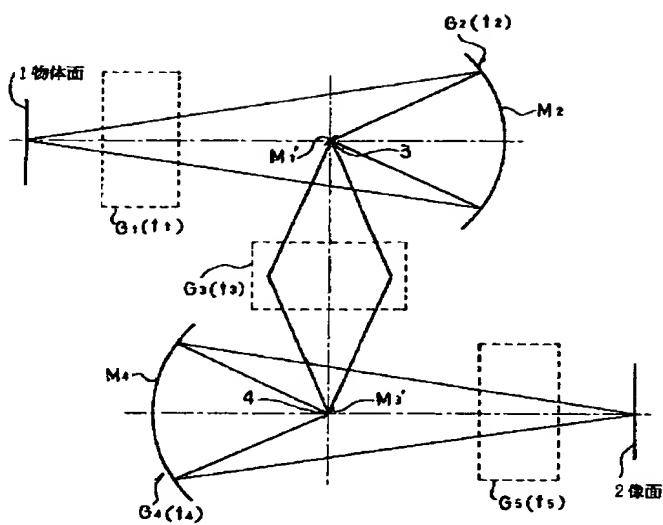
【図3】



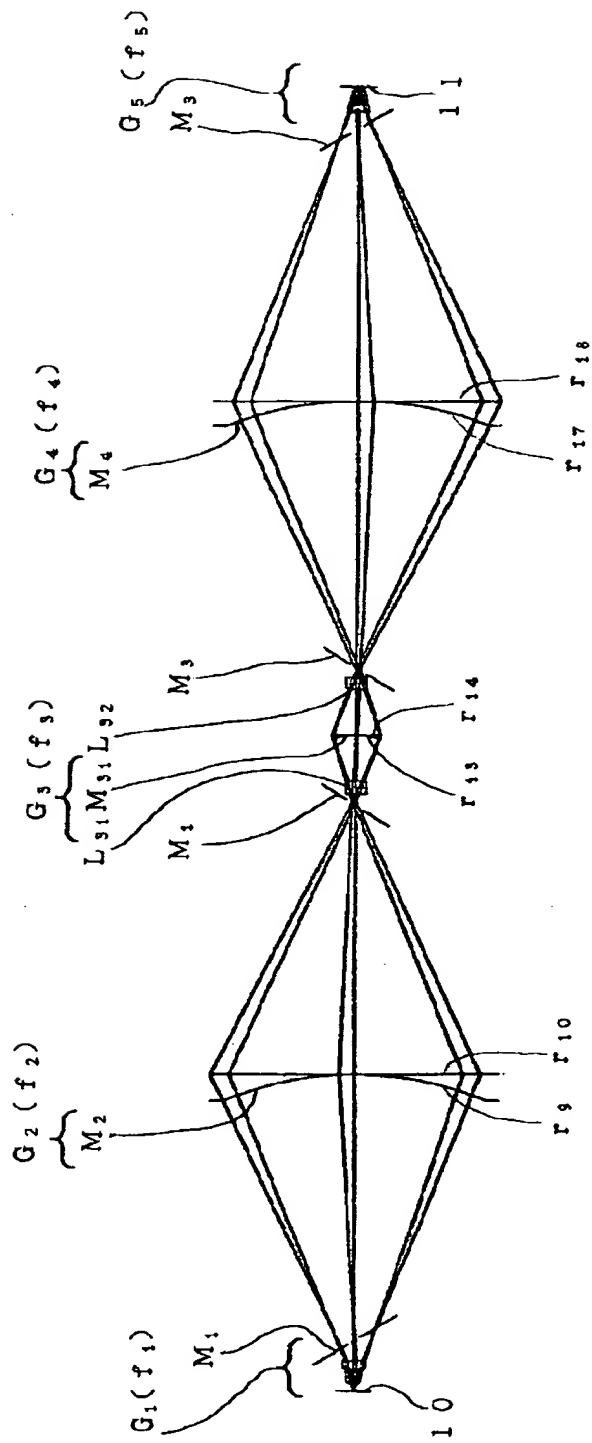
【図4】



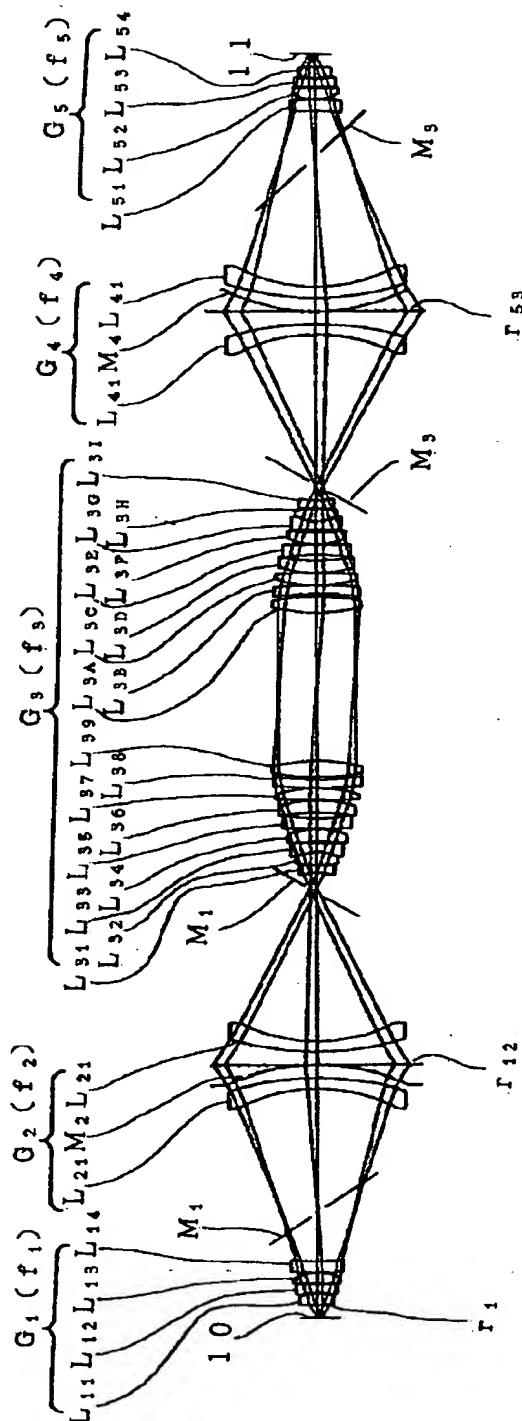
【図5】



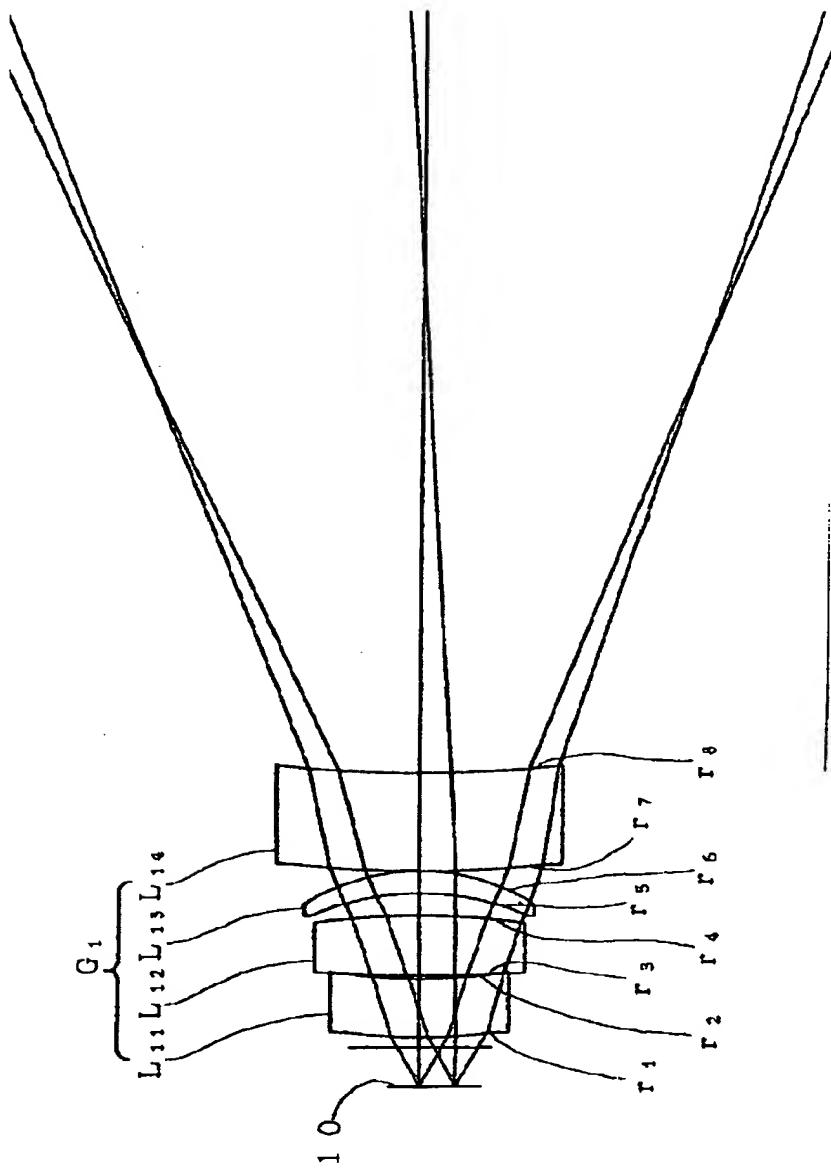
【図6】



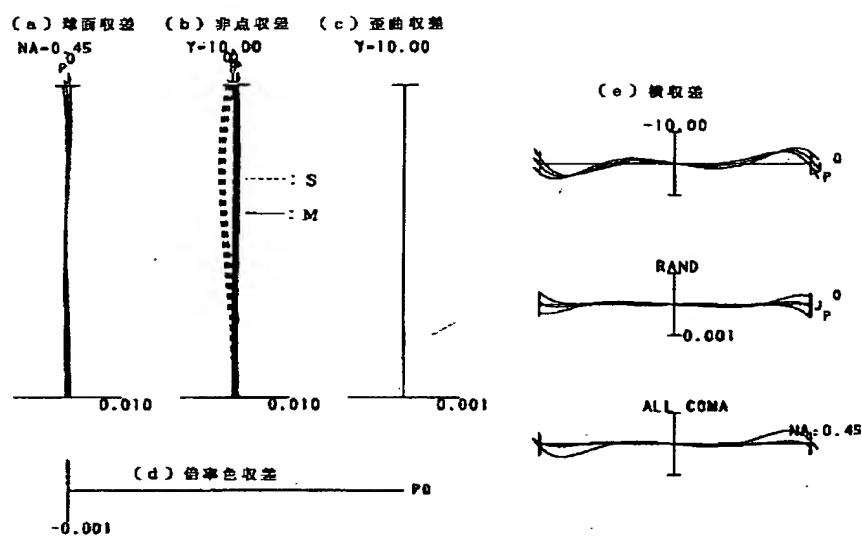
【図9】



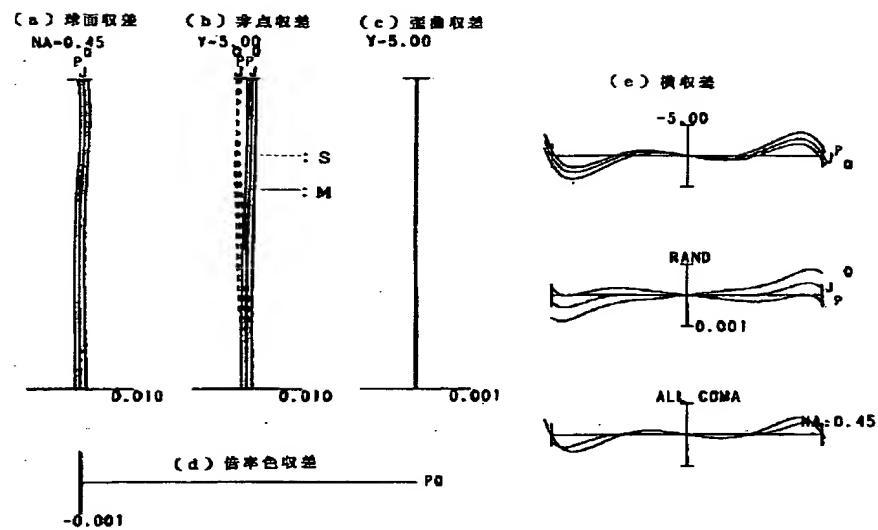
【図7】



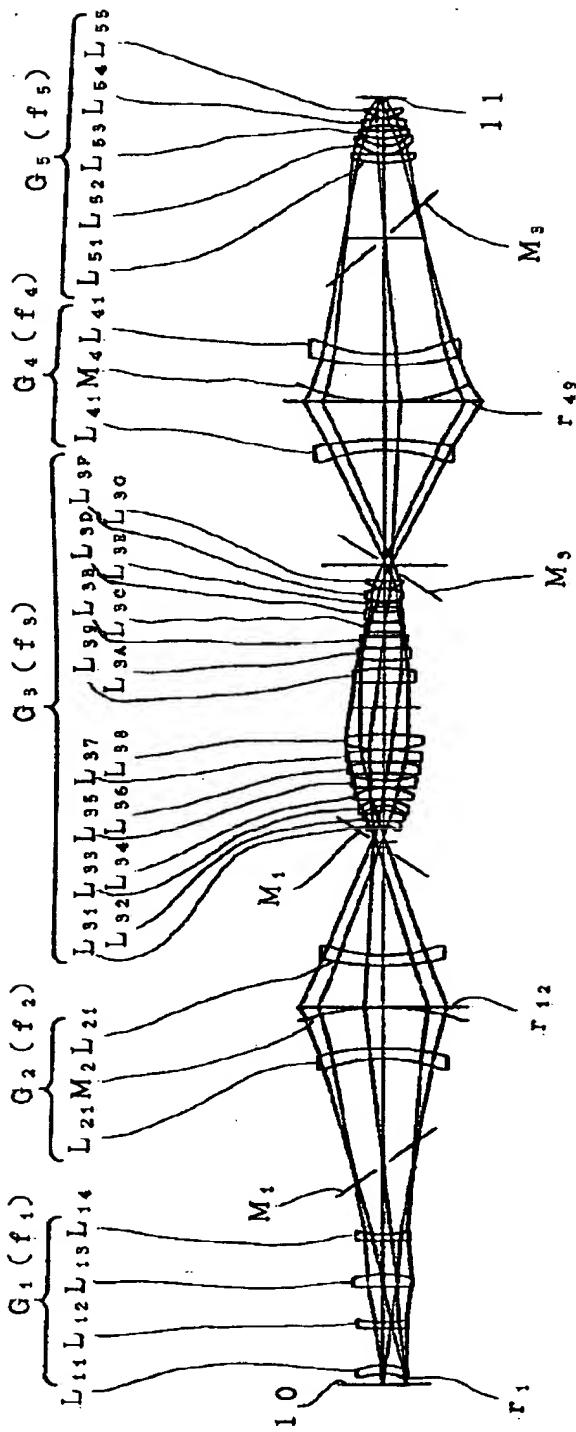
[図8]



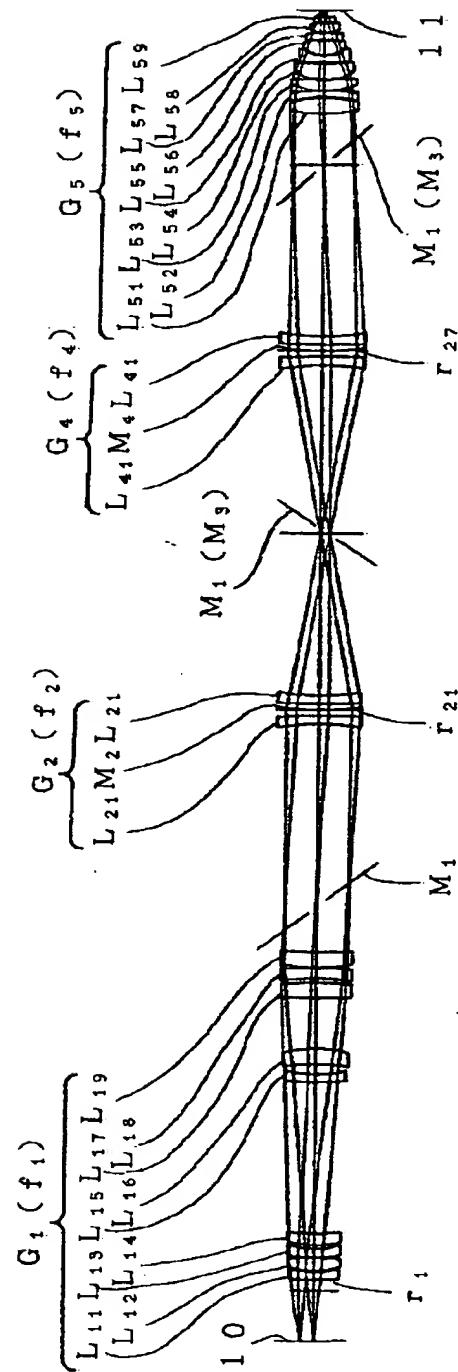
[図10]



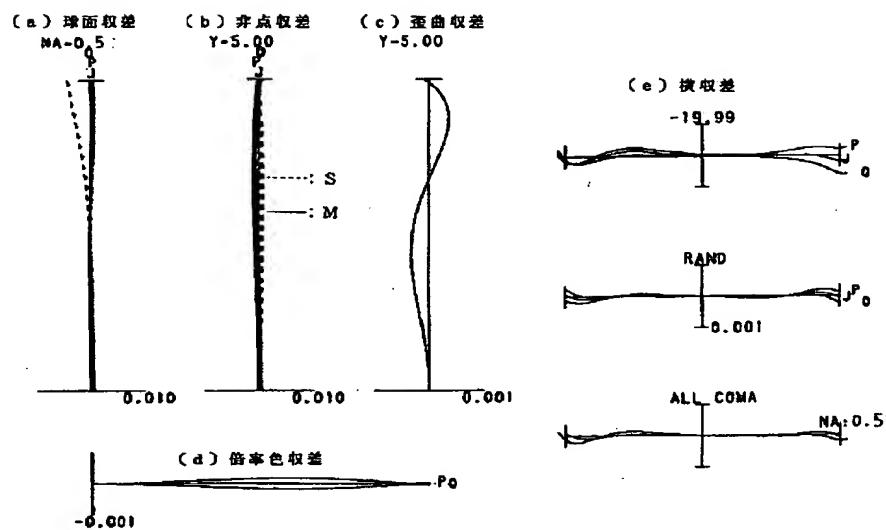
【図1.1】



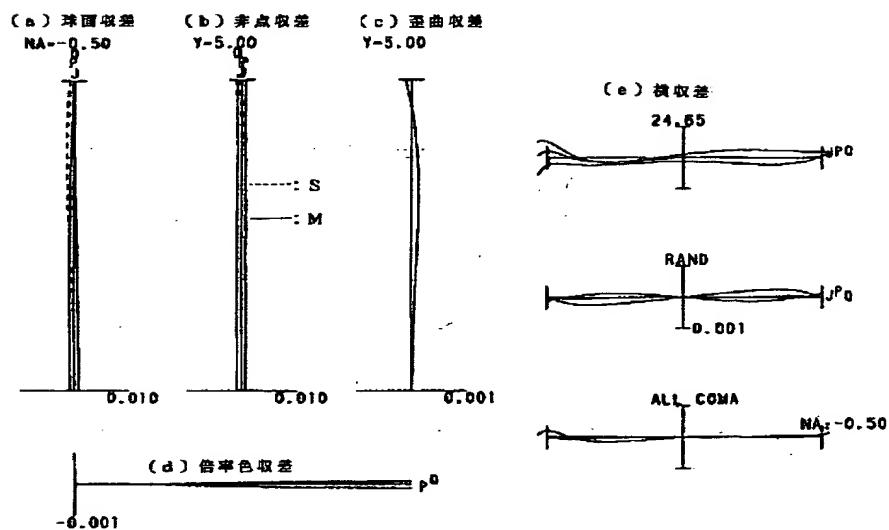
【図1.3】



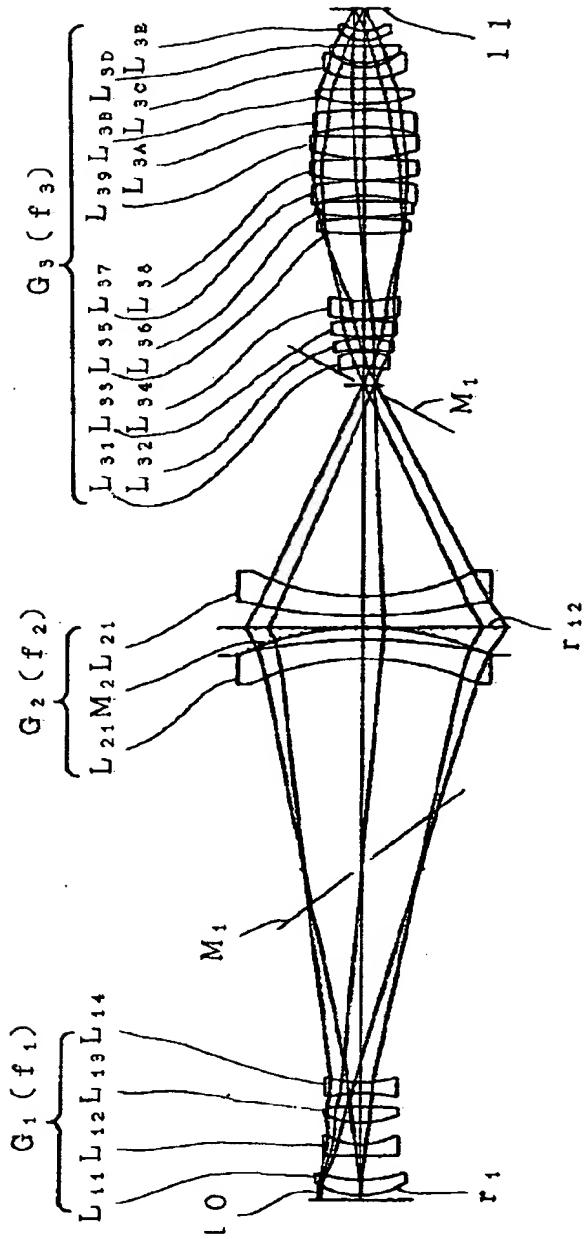
【図1.2】



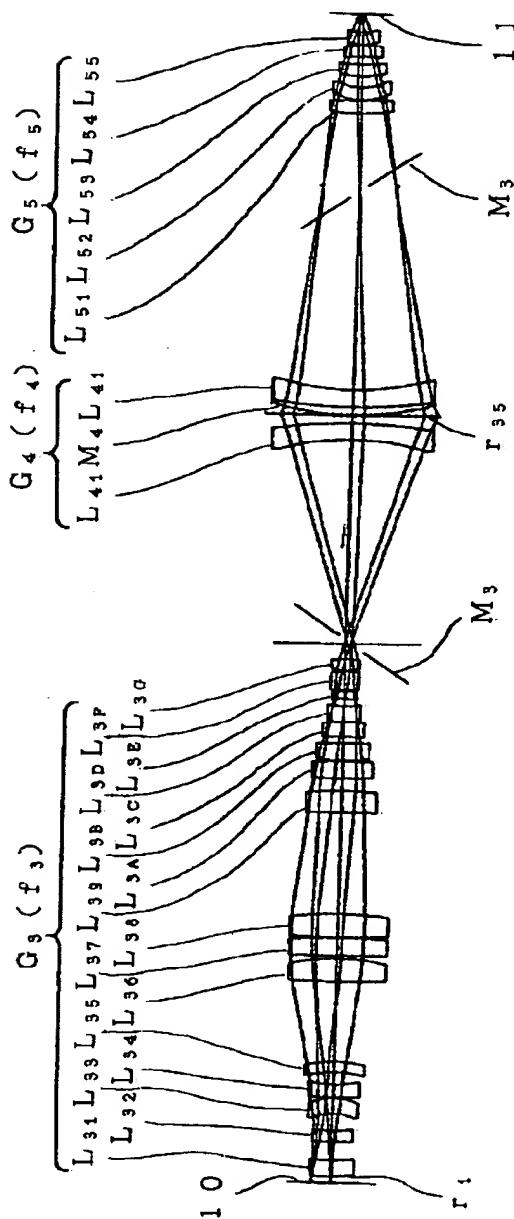
【図1.4】



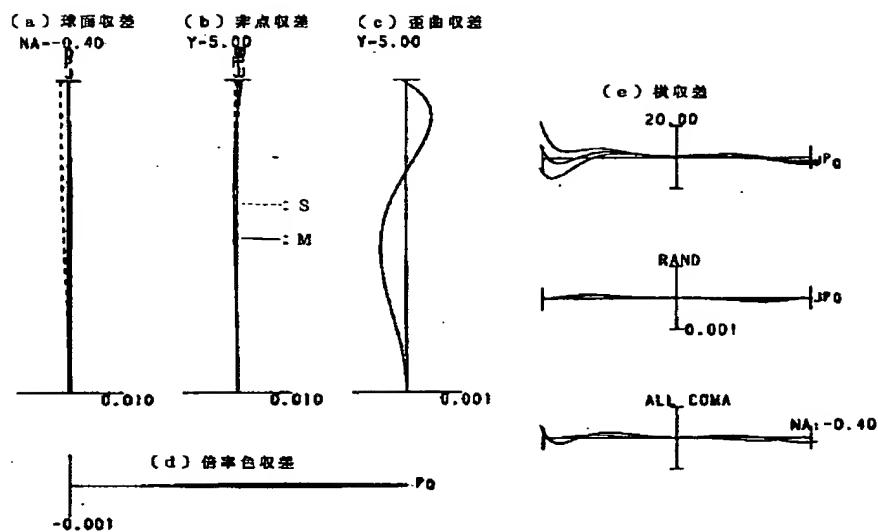
【図15】



【図17】



【図16】



【図18】

